

Intertidal Reconnaissance Survey to Assess Composition, Distribution, and Habitat of Marine/Estuarine Infauna in Soft Sediments in the Southwest Alaska Network



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ACRONYMS

C:N – Carbon:nitrogen ratio
GPS – Geographic Positioning System
KATM – Katmai National Park and Preserve
KEFJ – Kenai Fjords National Park
LACL – Lake Clark National Park and Preserve
MLLW – Mean Lower Low Water
NP – National Park
NPS – National Park Service
PGS – Particle grain size
ppt – parts per thousand
SWAN – Southwest Alaska Network of the NPS
TKN – Total Kjeldahl Nitrogen
TN – Total Nitrogen
TOC – Total Organic Carbon

Cover photos: Top, sand tombolo west of Ninagiak Island, KATM, William Driskell; Top right, feeding brown bear, softshell mudflat in front of Katmai Wilderness Lodge, KATM, Dennis Lees; Bottom right, large cockle and surfclam shells, SG1, LACL, William Driskell; Bottom left, *Enteromorpha*-covered softshell mudflat, S8, LACL, William Driskell; Top left, Aialik Glacier from W10, KEFJ, Dennis Lees; Center, razor clam beach with site layout, SG2, LACL, Dennis Lees.

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ABSTRACT

Soft sediments on beaches in three parks in the Southwest Alaska Network (SWAN) were examined to provide baseline data on infaunal assemblages, especially bivalves. The surveys were conducted in Kenai Fjords National Park (KEFJ), Lake Clark National Park and Preserve (LACL), and Katmai National Park and Preserve (KATM) were examined using a variety of sampling techniques often employed on soft substrata. These included 1/4-m² (2.7 ft²) and 1/16-m² (0.67 ft²) macrobivalve excavations, microbivalve core samples, and visual assessments to assess species composition and distribution of the infauna, especially bivalves used for prey by important predators (esp. brown bears (*Ursus arctos*), sea otters (*Enhydra lutris*), diving ducks (e.g., *Melanitta* spp., *Histrionicus histrionicus*, and *Clangula hyemalis*), and shorebirds (e.g., *Calidris* spp.)), as well as visual evidence of recent predation. Samples were collected at 39 of 56 sites in KEFJ, 9 of 21 sites in LACL, and 13 of the 31 sites in KATM.

Soft intertidal habitats in KATM are quite diverse, varying from clean fine sand on the exposed beaches to compact sandy mud in protected areas in Kamishak Bay. Habitats differ substantially within and among the parks. Sediments in KEFJ are dominated by gravel with substantial quantities of sand or silt. In contrast, very few gravel or mixed-soft sediments were observed in KATM although they appeared biologically rich where they occurred. In contrast, habitats in the northern region of KATM, dominated by sand or mud, are quite similar to those observed in LACL but wave exposure in KATM may have created harsher environments. Generally, beaches in KEFJ appear to be considerably younger than those in KATM or LACL.

The bivalve faunae differed considerably within and among regions in KATM, but dominant bivalves within the regions also dominated within either KEFJ or LACL. Potential target species common in KATM and KEFJ included butter and softshell clams (*Saxidomus giganteus* and *Mya arenaria*), Baltic macomas (*Macoma balthica*), and foolish mussels (*Mytilus trossulus*). Potential target species common in KATM and LACL included razor, surf, and softshell clams and Baltic macomas (*Siliqua* spp., *Mactromeris polynyma*, *Mya* spp., and *Macoma balthica*).

Among the three parks surveyed, KATM exhibited the highest diversity in habitats and bivalve assemblages. All parks supported bivalve population that could support a long-term monitoring program and exhibited evidence of predation by major foraging species like brown bears, sea otters, and diving duck.

EXECUTIVE SUMMARY

As part of a program to develop a long-term monitoring program in the national parks comprising SWAN, we examined soft sediments on beaches in Kenai Fjords National Park (KEFJ) and Lake Clark National Park and Preserve (LACL) in 2004 and Katmai National Park and Preserve (KATM) during 2005. The objective of this reconnaissance survey was to assess species composition and distribution of the infauna, obtain information that will be used to design the sampling program and select species for long-term monitoring, and make recommendations on how that program should be structured. Although samples were collected to provide insight into the microinfauna, the focus of the program was on several larger (macrofaunal) bivalves used for prey by important predators in SWAN (esp. brown bears (*Ursus arctos*), sea otters (*Enhydra lutris*), and diving ducks (e.g., *Melanitta* spp., *Histrionicus histrionicus*, and *Clangula hyemalis*)).

Samples were collected at 39 of 56 sites in KEFJ, 9 of 21 sites in LACL, and 13 of the 31 sites in KATM. In KEFJ, samples were collected to examine a variety of habitat types and to provide insight into the north-south gradient within the fjords and the east-west gradient among fjords. In KATM, sites were sampled to provide insight into a north-to-south gradient for sediment type, habitat, and exposure and to examine a variety of habitat types. In LACL, where we already had previously conducted considerable research, we surveyed and/or sampled a number of sandy and muddy habitats in areas we had not previously visited.

We used a variety of sampling techniques which included 1/4-m² (2.7 ft²) and 1/16-m² (0.67 ft²) macrobivalve excavations, microinfaunal core samples, composited sediment samples for particle grain size, organic carbon and nitrogen analysis, and visual assessment to assess species composition and distribution of the infauna, especially larger bivalves used as prey by important predators (esp. brown bears, sea otters, and diving ducks). We recorded site descriptions, water temperature and salinity, and noted visual evidence of recent predation. Finally, we recorded field observations and GPS coordinates and took photographs to document the location and appearance of the sediments and habitats, including burrow and shell debris, and other relevant aspects such as species composition.

Habitats and biological diversity vary substantially within and among the three parks. These features are markedly less diverse in LACL and the northern and central regions of KATM, which are dominated by long stretches of very exposed sandy beaches. In contrast, KEFJ and the southern region in KATM are characterized by small and large bays. The shoreline in KEFJ and southern KATM has large and small pocket beaches, numerous islands, and elevated protected lagoons with mud or sand flats. The geographic complexity in KEFJ and the southern region in KATM creates a wide range of exposures that, in turn, results in relatively greater habitat diversity than is observed in LACL or northern KATM. Nevertheless, habitats in southern KATM are substantially different from

those observed in KEFJ whereas the soft habitats and the bivalve fauna in the northern region are quite similar to those observed in LACL. Because it has features in common with both LACL and KEFJ, habitat diversity is higher in KATM than in the other two parks.

The nature of the beaches, their sediments, and the bivalve assemblages living in them, appears strongly influenced by their widely varying geologic histories and climatologic and oceanic characteristic. Likely due to glacial retreat, the beaches in KEFJ appear younger than in either KATM or LACL. Consequently, the sediments in KEFJ are generally coarser than in KATM and especially LACL. The beaches in LACL appear to be exposed to the most rigorous physical processes, a condition well reflected in the low diversity of the bivalve fauna inhabiting its beaches and mud flats.

Bivalves are particularly suitable for use as sentinel species because, by filtering seawater to obtain their nutrition, they can concentrate contaminants by a factor of several thousand. Like the sediments, the bivalve faunae also differed substantially among the parks. In KEFJ, potential sentinel species included foolish mussels (*Mytilus trossulus*), Baltic macomas (*Macoma balthica*), littleneck and butter clams (*Protothaca staminea* and *Saxidomus giganteus*), and two species of softshell clams (*Mya arenaria* and *M. pseudoarenaria*). In KATM, the sentinel species included butter clams, two species of softshell clams, foolish mussels, Alaska razor clams (*Siliqua alta*), and Baltic macomas. In LACL, principal species included Baltic macomas, Pacific razor (*Siliqua patula*), and softshell clams. In fact, the latter were the only species collected in samples in LACL during this survey.

We observed considerable predator foraging activities, particularly in KATM. The principal “charismatic” species, i.e., species that are especially appealing to humans, were the brown bear and the sea otter. Foraging bears and forage pits were observed throughout KATM. Although brown bears were common on or near the beaches in LACL, we did not observe appreciable evidence of foraging. In KEFJ, we only observed black bears and saw no evidence of foraging pits. Sea otters occurred in KEFJ and KATM but were more abundant in KATM, especially in the vicinity of Ninagiak Island and Shakun Islets. In Cook Inlet, they do not appear to venture as far north as LACL. Foraging pits dug by diving ducks were also widely distributed in all parks but mainly inside embayments or protected lagoons. Bears and otters generally appeared to concentrate on the larger clams such as butter, softshell, and razor clams, and foolish mussels whereas diving ducks focus on smaller bivalves such as Baltic macomas and smaller foolish mussels.

In the vicinity of Swikshak and Big River (KATM), our inability to find evidence of adult razor clam populations or foraging areas using that resource raises several intriguing questions regarding clam resources in KATM. The populations at Swikshak were adequate to support a commercial fishery until the mid-1960s, when the Great Alaska Earthquake destroyed the last local clam cannery (Johnson 2002). Intriguing questions arising from this inability include: Were the

adult razor clam populations destroyed by the earthquake or have they since dwindled? If the latter, what caused that decline? If not, where are they located and why are the bears apparently not utilizing them?

KEY WORDS

Infauna; bivalve; inventory; intertidal; Southwest Alaska Network, Katmai National Park and Preserve; Kenai Fjords National Park; Lake Clark National Park and Preserve; butter clam; Baltic macoma; oval Macoma; foolish mussel; softshell clam; false softshell clam; Pacific razor clam; Arctic hiatella; Alaska razor clam; Arctic surf clam; *Saxidomus giganteus*; *Macoma balthica*; *Macoma golikovi*; *Mytilus trossulus*; *Mya arenaria*; *Mya pseudoarenaria*; *Siliqua patula*; *Siliqua alta*; *Mactromeris polynyma*; *Hiatella arctica*.

INTRODUCTION

General

Littoral Ecological & Environmental Services (LEES) conducted intertidal reconnaissance surveys in three national parks within the Southwest Alaska Network (Kenai Fjords National Park (KEFJ), Lake Clark National Park (LACL) and Preserve, and Katmai National Park and Preserve (KATM) during the summers of 2004 and 2005 for the National Park Service (NPS; Figure 1). The purpose of the study was to provide inventories of the infauna, especially bivalves, living in unconsolidated substrata (soft sediments). These data also will be used to assist in the design of a long-term monitoring program for the parks within the SWAN and assist in selection of monitoring species.



Figure 1. Areas visited in the Southwest Alaska Network National Parks during the 2004 and 2005 intertidal reconnaissance surveys.

The overall goal of the project was to increase our understanding of infaunal communities across the range of soft-sediment habitats in the SWAN. This knowledge is needed to support decisions concerning the protection of these coastal resources. Information from the project will also be used to assess the practicality of including infauna as a component in the network's long-term, vital-signs monitoring program and to design a long-term monitoring program. The existence of such a program would have been helpful in explaining a puzzling finding during this reconnaissance survey, i.e., the apparent absence of adult clams from beaches at Swikshak and Big River, beaches where razor clams were harvested commercially until the Great Alaska Earthquake destroyed the cannery in Kodiak in 1964 (Johnson 2002). Our inability to find mature beds of razor clams on these beaches is quite perplexing.

This project was designed to provide a significantly better understanding of intertidal coastal resources of the SWAN parks. When incorporated into the network's Geographic Information System (GIS) and coastal databases, it will provide information that can be used to interpret existing and future data on sediment quality characteristics and the distribution and foraging ecology of shorebirds (*Calidris* spp.), sea ducks (*Melanitta* spp., *Histrionicus histrionicus*, and *Clangula hyemalis*), brown bears (*Ursus arctos*), sea otters (*Enhydra lutris*), and other species.

Coastal resource monitoring programs can be costly and complex. For these reasons, the selection of which variables to monitor is an important issue from both the scientific and management viewpoints. Not all species or habitat variables are equally valuable or useful for long-term monitoring. Thus, by selecting and monitoring fewer, more appropriate species and variables, the spatial extent of monitoring can be extended and site-specific replication increased. The intent of this study was to define these options and provide a framework and design for repeatable, quantified monitoring. Moreover, it characterized intertidal infaunal communities and provided an assessment of habitat quality. These data will enable future comparisons for detection of long-term changes in biota and habitats resulting from geomorphic processes, water-quality changes, catastrophic natural events, or the effects of human actions.

Background

The marine coastlines of Aniakchak National Monument, Katmai National Park and Preserve, Kenai Fjords National Park, and Lake Clark National Park (Southwest Alaska Network) extend for 1,920 km (1,200 miles) along the Northern Gulf of Alaska. Soft-sediment intertidal habitats (e.g., mud flats and sand flats) characterize approximately 43 percent of this coastline. Habitats range from broad sheltered tidal flats to steep, high-energy, cobble beaches to lagoons at the heads of narrow bays and fjords.

Intertidal mud flats and sand flats support highly productive habitats and populations of littleneck and butter clams (*Protothaca staminea* and *Saxidomus giganteus*), Arctic surfclams (*Mactromeris polynyma*), macomas (*Macoma* spp.),

softshelled clams (*Mya* spp.) and other invertebrates. The invertebrates, in turn, provide a critical prey resource for shorebirds, ducks, fish, bears, sea otters, and marine invertebrate predators. For example, mud flats along Lake Clark National Park support up to 100,000 migrating western sandpipers (*Calidris mauri*) and dunlins (*Calidris alpina*) during spring migration (Bennett 1996). While within the park, both species feed almost exclusively on Baltic macomas in the mud flats. Moreover, Baltic macomas on mud flats are the primary forage item for rock sandpipers overwintering in Cook Inlet during the winter (Gill and Tibbitts 1999). Macomas and mussels are also important food sources for waterfowl such as greater scaup (*Aythya marila*), oldsquaw (*Clangula hyemalis*), surf scoter (*Melanitta perspicillata*), and black scoter (*M. nigra*), which feed on the mud flats throughout the winter (Sanger and Jones 1984, Lees et al. 1980). At Katmai National Park, brown bears forage in estuaries and on the sand beaches during much of the year, grazing on sedge and digging clams on tidal flats. Sea otters forage for large bivalves (especially littleneck, butter, and softshell clams) during high tides on suitable intertidal substrates in Katmai and Kenai Fjords National Parks. These beaches also provide valuable spawning and nursery habitats for juvenile salmonids, forage fish, and crustaceans.

The plant and animal communities of intertidal mud flats and sloughs serve as critical connections between nearshore marine waters and inland wetlands, rivers, lakes, and glaciers. Most of the predators are mobile or migratory. Non-migratory species such as Common Ravens (*Corvus corax*) and bears forage in the intertidal and subsequently export nutrients and biomass to other biological communities, connecting local intertidal and terrestrial ecosystems. Migratory species such as shorebirds and ducks export nutrients to distant, often upland, habitats.

In addition to their trophic importance, bottom (benthic) organisms possess many characteristics that make them useful indicators of environmental stress or change in the nearshore marine environment. They have a broad range of physiological tolerances but feeding and reproductive modes are limited. Because benthic organisms are relatively sedentary, they cannot readily escape sediment contamination or changing environmental conditions. For these reasons, benthic organisms often show measurable responses to environmental stress or change. Bivalve tissue concentrations are probably the most suitable indicator for long-term trends of many contaminants along park coastlines and, because of the biomagnification and temporal integration factors, bivalves represent a preferable alternative to water or sediment samples for contaminant analysis. Roman et al. (2003) strongly recommended sampling benthic marine macro-invertebrates at least once every five years in support of monitoring core water quality variables in National Parks.

Although marine/estuarine benthic resources are large and ecologically important components of the coastline, they are also the least well known. While a number of infaunal communities has been surveyed in or near network parks, most have involved spatially-limited descriptive analysis of species abundance, generally in

connection with some existing or planned perturbation (offshore oil and gas leases, Exxon Valdez Oil Spill, and dredging).

Within the Lake Clark National Park, the initial studies in intertidal habitat currently located occurred in Chinitna Bay in 1976 during a reconnaissance survey of lower Cook Inlet for the NOAA Outer Continental Shelf Environmental Assessment Program (Lees and Houghton 1977). Several areas examined along the north side of the bay, extending from Spring Point to Glacier Spit, provide qualitative descriptions of rock, sand, and mud habitats in the bay. Black bears were observed foraging on the beach during this survey. The rocky substrata supported a typical epibiota but it was somewhat impoverished compared to those observed in Kachemak Bay or along the Gulf of Alaska. Sand substrata supported a razor clam assemblage similar to those observed at Polly Creek and Clam Gulch, farther north in Cook Inlet. Mud substrata supported a productive suspension-feeding assemblage dominated by softshell clams, Baltic macomas, and a large burrowing echiuran worm. In subsequent years, studies conducted on the mud flat at Glacier Spit examined seasonal and vertical patterns in abundance, biomass, recruitment, and diversity, as well as growth of several clam species (Baltic macomas, softshell clam species, basket cockles [*Clinocardium nuttallii*], and montacutids [*Neaeromya* (= *Pseudopythina* sp.)]; Lees et al. 1980) indicated that densities varied considerably over the 18 months of the sampling. Moreover, it appeared that recruitment of the bivalves varied considerably among the potential recruitment periods surveyed (Figure 2). The Baltic macoma population was relatively stable between years (coefficient of variation [CV] = 0.34 over the survey period), followed by the softshell clam *Mya arenaria* (CV = 0.42). Other species of softshell clam were more variable (CV = 0.81 and 0.95, respectively, for false softshell and a third softshell clam). Variability was highest (CV = 1.76) in the basket cockle, which experienced a significant recruitment event before the last sampling period. Biomass also varied considerably during this study but somewhat less than abundance because of the relative stability of the larger softshell clams.

Additional studies have been conducted in the Lake Clark National Park. The National Park Service collected specimens of Baltic macoma populations on the north and south sides of Tuxedni and Chinitna Bays in 1996 for hydrocarbon and trace metals analyses of *Macoma* tissues (KLI 1996). The Cook Inlet Regional Citizens Advisory Council (CIRCAC) conducted a reconnaissance survey in middle and upper Cook Inlet that included sites in Chinitna and Tuxedni Bay (Lees et al., in prep.) Similar assemblages were observed at upper elevations in mud flats in these bays. In addition, assemblages representative of sandy beaches were observed on beaches closer to the mouth of Chinitna Bay.

Information on infaunal assemblages in the Kenai Fiords National Park is sparse. Limited descriptions of these assemblages provided for areas west of the park (Koyuktoalik Bay and Port Dick) indicate that sea ducks and sea otters forage on these beaches (Lees and Rosenthal 1977). Since 1993, the Prince William Sound Regional Citizen's Advisory Council (PWSRCAC) has been analyzing hydrocarbon concentrations in mussels in Aialik Bay twice a year as part of its

Long-Term Environmental Monitoring Program but has not been surveying abundance of mussels or clams (Payne et al. 1998, 2005).

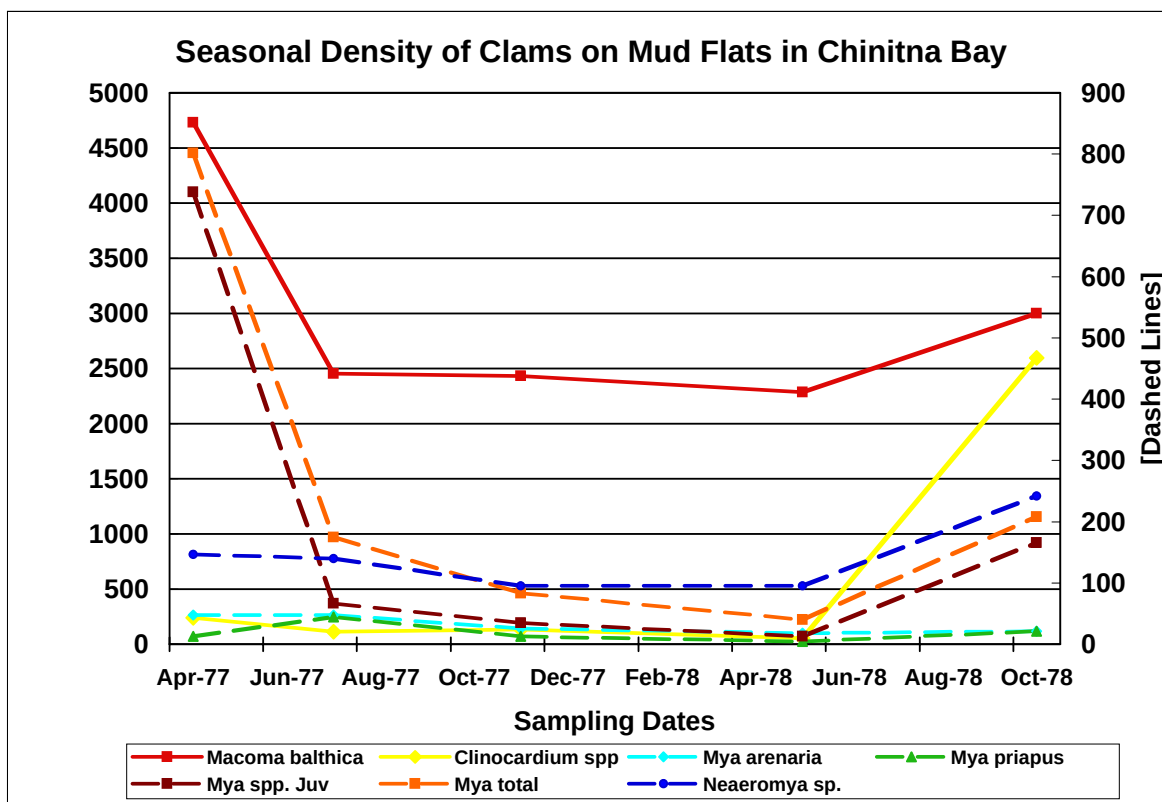


Figure 2. Seasonal density patterns for several clams in mud flats at Glacier Spit, Chinitna Bay (based on Lees et al. 1980).

Information for infaunal assemblages on beaches in Katmai National Park is also sparse. Lees and Houghton (1977) provided descriptions of the intertidal infauna in the vicinity of the mouth of the Douglas River. Recent ground-truth surveys of intertidal habitats in Katmai National Park in 2003 concentrated on rocky shores but clam assemblages were examined qualitatively on several unconsolidated beaches (personal observation, DCL). It was apparent from these limited surveys that clam assemblages are well developed on numerous beaches and are heavily exploited by sea ducks, brown bears, and sea otters.

The objectives of the project were to:

- 1) Determine the composition and distribution of intertidal invertebrate species, especially bivalves, inhabiting soft-sediment beaches and flats in the SWAN parks.
- 2) Characterize abiotic factors that can influence occurrence, distribution, and relative abundance of intertidal infaunal organisms, such as sediment properties, exposure, and tidal inundation.

- 3) Identify candidate target species for long-term monitoring based on distribution, abundance, sensitivity to habitat change, ecological importance, and ease of sampling.

Earlier reports partially described the findings of the surveys in KEFJ, LACL, and KATM (Lees and Driskell 2004, 2006). These reports generally characterized the sediments characteristics and macrofaunal bivalves (from excavation samples) of the sampling sites and regions. These descriptions are summarized in Appendices A – C. Objectives of this report are to:

- 1) Provide an integrated view of the bivalve assemblages in and on the sediments in the parks surveyed and describe the relationships among the bivalve assemblages;
- 2) Describe sedimentary patterns in the parks;
- 3) Discuss the factors influencing the distribution and abundance of the bivalve species and contrast the abundance patterns in the parks and sediments; and
- 4) Identify candidate species that could be used in the proposed long-term sampling program in each park.

In this report, we will summarize and compare the numerical and biological characteristics of the three parks and illustrate the structural relationships indicated by species composition patterns using cluster analysis to demonstrate relationships among site and species groups.

METHODS AND MATERIALS

A Bell Jet Ranger helicopter was used to access most sites in LACL and KATM and, while in KEFJ, skiffs from the National Park Service vessel *R/V Serac* were used to access beaches. We surveyed KEFJ from 30 May through 7 June 2004 with a field crew of six individuals. Dividing this crew into two teams in separate skiffs enabled us to survey two beaches at a time. Three members of this team had moderate to extensive experience surveying infauna on soft beaches in southcentral Alaska. Three crew members were NPS employees with minimal experience in surveying beaches or infauna. In LACL, we surveyed by helicopter from 30 June through 2 July 2004 with only a three-person team, all with considerable experience in surveying infauna on soft beaches. In KATM, we surveyed by helicopter from 22 through 25 June 2005 with a three-person team, two of whom had extensive experience at surveying infauna on soft beaches in southcentral Alaska. One member of the team was an NPS employee.

Site Selection

Prospective sites in the three parks were identified based on an extensive evaluation of ShoreZone maps, NOS navigation charts, and aerial photographs

as well as geomorphologic data that are available for the park. Navigation charts and ShoreZone maps were used to identify areas with soft sediments that could be suitable for the rich intertidal infaunal assemblages that support important predators.

Final site selection was made in collaboration with NPS managers based on a review of recently completed aerial video imaging for the coastlines of all parks in the SWAN by Harper (2003). These imaging surveys were conducted at low tide, with simultaneous classification of intertidal geomorphology and biology. This mapping product characterizes the general geomorphology (substrata) and biological habitat types (primarily algal) for the rocky intertidal habitats. Information is stored in a digital geographic information system (GIS). This resource provides a very useful means of evaluating abundance of various habitat types, as well as an aerial view of the habitat, and provides insight into the potential for sampling success at candidate sites.

Sampling Methods

Samples generally were collected from a single elevation at mud flat, sand- or gravel-beach sites. We attempted to sample at or above approximately 2.4 m (8 feet) above MLLW on mud flats and approximately MLLW to 0.6 m (2 feet) below MLLW on sand, gravel, or mixed-soft beaches. Because the profile of beaches and mud flats varies according to exposure, substratum, and season, however, we determined final sampling locations and elevations on site at the time of the survey. In many cases, because the most appropriate sampling locations were located several feet above water level or below the high tide line, used as elevation reference points, the sampling elevation recorded was a rough approximation.

Our sampling methods during the field effort included excavation of 0.25-m² (2.7-ft²) quadrats to a depth of 15 cm (6 in) in soft sediments, removal of mussels from 0.0625-m² (0.67-ft²) quadrats in mussel beds, or enumeration of clam “shows” and other species-identifiable burrows in 0.25-m² quadrats, and collection of infaunal core and sediment samples. To reduce costs, replication of the excavations and infaunal core samples was limited to three random samples of each type per site. The total surface area sampled by triplicate excavation sampling was 0.75 m². With excavation sampling, the intent was to provide a reasonable estimate of the species composition, abundance, and size structure of populations of the larger, longer-lived infauna, particularly bivalves. We sieved materials excavated from these plots through 6.35-mm (0.25-in) mesh hardware cloth. Excavation samples were either processed in the field each day or frozen for transport to the laboratory for processing.

The smaller infauna missed with the excavation method were sampled with a 10-cm. (4-in.) diameter core sampler inserted 15 cm. (6 in.) into the sediment (surface area = 0.008 m²). The intent was to provide insight into the species composition, abundance, and size structure of populations of the smaller, short-

lived bivalves and the juveniles of the long-lived species. The total triplicate-sampled surface area was 0.024 m².

Core samples were screened on 1-mm mesh sieves to separate the infauna from the sediment and reduce the volume of sample requiring preservation and shipment. Animals remaining on the screens were labeled and preserved for laboratory identification, enumeration, and measurement in the laboratory. These samples were fixed in a 10-percent solution of buffered formalin in seawater. Within a few weeks of fixation, the infaunal samples were washed and transferred into 70-percent isopropyl alcohol for preservation.

We focused on assessing bivalve assemblages, and especially those larger species targeted by local “charismatic” (e.g., bears and sea otters) and migratory (e.g., shorebirds and sea ducks) predators but core samples were also collected to provide a broader understanding of the infaunal assemblages, especially recent recruitment. Three sampling locations for both excavations and infaunal cores were determined randomly along a 30-m transect line laid out parallel to the shoreline at each site. We placed transect lines in locations that hopefully maximized the density estimates for the infaunal bivalves based on clam “shows”, feeding marks, depressions, or siphon burrows indicating the presence of clams.

In areas where siphons or biogenic activities of individual organisms produced distinguishable surficial cues, we used band-transect or quadrat-sampling techniques to provide density data for the organisms creating the burrows or for the disturbance indicating the activity (e.g., forage pits). Species sampled in this manner include softshell and razor clams, and fat innkeeper worms (the echiuran *Echiurus echiurus*). In a few cases, we also enumerated feeding pits resulting from feeding activities of brown bears or sea otters. We employed a variety of dimensions for sampling plots during these surveys. Each size was chosen based on a visual impression of the density of the features at the specific site. The intent was to optimize the effort. Plot sizes ranged from 0.25-m² quadrats to 1- X 61-m band transects. The band transects were established by deploying a transect line for the prescribed distance and then enumerating and recording features of interest within a prescribed distance (1-2 m) of the transect line.

We collected composite sediment samples comprising aliquots from surficial sediments adjacent to each infaunal sample for analyzing sediment variables. To reduce analytical costs, these aliquots were combined into a single composite sample for each site. Sediment samples were frozen at the completion of each sampling day.

We collected three types of environmental information at each site, i.e., a written site description, water temperature and salinity, and photographs. The site description included: 1) GPS coordinates of site locations; 2) descriptions of sediment types and 3) exposure regime and orientation; and 4) a general description of the biological assemblages occurring at the site. GPS coordinates were collected with hand-held WAAS-enabled GPS units capable of 3- to 8-m

(10- to 26-ft.) accuracy. The datum for all coordinates provided below is Alaska Albers Projection of the NAD27. Initially, we measured temperature and salinity of the surface water near the sampling site. While sampling in KEFJ, we concluded that quality of interstitial water was equally important. Subsequently, we measured these variables in the water seeping into a hole dug in the sediment at the sampling site. These variables were measured by immersing a Yellow Springs Instruments SCT 30 probe. Finally, we photographed panoramas and pertinent features to document current sediment conditions of various morphological features, the beach profile, and the associated biological assemblages, as appropriate. The photographs were taken with non-georeferenced digital cameras. Generally, the photographs from a site were taken within 30 m of the GPS coordinates listed for a site and often from the headstake of the transect. These photographs have been labeled and are archived in the NPS database with appropriate descriptive captions as metadata. They have also been retained in the archives of the authors of this report.

We did not survey beach profiles because the time required conflicted with our desire to examine as many sites as possible.

Sample Analysis

Organisms in the excavation and infaunal core samples were sorted to major taxonomic levels (e.g., polychaete, amphipod, mysid, etc.) but bivalves were further identified to species or lowest practical taxon, in the case of juveniles. Shell length of bivalves was measured to 0.1 mm (0.004 in) with digital calipers.

In the laboratory, sediment samples were analyzed to determine sediment grain size parameters, total organic carbon (TOC; KEFJ and LACL), total carbon (TC; KATM), total Kjeldahl nitrogen (TKN; KEFJ and LACL), or total nitrogen (TN; KATM). Particle size measurements were obtained according to the methodology of Plumb (1981) and ASTM D422 63. TOC was analyzed by EPA Method 9060. TKN was analyzed by the EPA Method 351.3. TC and TN were analyzed with a carbon/nitrogen autoanalyzer using SW-826, a method similar to EPA 9060, but the samples are not acidified. NIST standards were run with the samples for quality assurance. Knowledge of these chemical properties is helpful in understanding the nutrient regime within which the infaunal organisms live.

Statistical Analysis

Species diversity was measured using Simpson and Shannon-Wiener diversity indices. The complementary form of the Simpson index employed is given by:

$$D = 1 - \sum (p_i)^2 = 1 - \sum [(n(n-1))/(N(N-1))],$$

where p_i is the proportion of the total number of individuals ($\sum n_i$) observed in the i^{th} species.

This index, ranging from 0 (low diversity) to 1 (high diversity), places emphasis on common species (Krebs 1998). The value of D reflects the number of equally common species required to generate the observed heterogeneity in the sample.

In contrast, the Shannon-Wiener diversity index (H') represents the number of information bits per species and places greater emphasis on the rarer species. H' is defined as:

$$H' = -\sum_{i=1}^S (p_i)(\log_2(p_i)) = -\sum_{i=1}^S (n_i/N)(\log_2(n_i/N)),$$

where s = number of species, n_i is the number of individuals in the i^{th} species, and N is the number of individuals in sample ($=\sum n_i$).

Cluster analysis was employed to elucidate relationships among sampling sites and among species. The analysis was performed on the entire species matrix from all three parks to illustrate differences and similarities within the parks and search for larger-scale relationships among species. We imported the species matrix into the software program, Le Proiciel R, to perform the calculations (Casgrain et al. 2005). Site or species similarity was quantified with the Czekanowski (= Sorenson) similarity coefficient. The similarity coefficients were then clustered with agglomerative hierarchical clustering using an unweighted arithmetic mean strategy.

For inferential testing, we used power analysis to determine the number of replicate samples necessary to optimize the likelihood of rejecting a true null hypothesis (Type I error) and accepting a false null hypothesis (Type II error). These analyses provide insights into potential sampling effort that could be required for the various sampling methods during the long-term monitoring program. The software package was PiFace, version 1.61, a series of Java applets developed by R. Lenth (1996, 2004).

RESULTS

We collected habitat and general biota descriptions at 56, 21, and 31 sites in KEFJ, LACL, and KATM, respectively, and sampled at 39, 9, and 13 sites. We observed a total of thirty species during these surveys (Table 1). These species represent eleven families of bivalves. Eight larger, less common species were observed only in the excavation samples whereas three common but small species were observed only in the core samples. Excavation sampling was better at detecting the presence of several large, long-lived but less common species than core sampling but misses common, small species because of the large sieve size.

The distribution of the sampling locations within each park is depicted in Figures 3 – 5. KATM included topographic and geological components similar to KEFJ in the southern region (fjords and deep embayments) and LACL in the central and northern regions (mud flats and extensive broad sand beaches). KEFJ was also

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topographically and geologically complex whereas LACL was substantially less complex (discussed below).

Table 1. Common and scientific names of bivalves observed visually (EL) or in excavation or core samples from SWAN parks in June 2004-2005. Species are listed phylogenetically by family.

Common Name	Scientific Name	Common Name	Scientific Name
Northern horsemussel	<i>Modiolus modiolus</i>	Foolish mussel	<i>Mytilus trossulus</i>
Silky axinopsid**	<i>Axinopsida serricata</i>	Rough dipledon	<i>Diplodonta impolita</i>
Suborbicular kellyclam*	<i>Kellia suborbicularis</i>	Compressed montacutid*	<i>Neaeromya ?compressa</i>
Robust mysella**	<i>Rocheftoria tumida</i>	Basket cockle	<i>Clinocardium nuttallii</i>
Broad smoothcockle*	<i>Serripes ?laperousii</i>	Kennerley venus*	<i>Humilaria kennerleyi</i>
Butter clam	<i>Saxidomus giganteus</i>	Littleneck clam	<i>Protothaca staminea</i>
Lord dwarf-venus**	<i>Nutricula ?lordi</i>	Minute turton**	<i>Turtonia minuta</i>
Alaska great-tellin*	<i>Tellina lutea</i>	Salmon tellin	<i>Tellina nukuloides</i>
Baltic macoma	<i>Macoma balthica</i>	Thick macoma*	<i>Macoma ?crassula</i>
Expanded macoma	<i>Macoma expansa</i>	Oval macoma	<i>Macoma golikovi</i>
?Pointed macoma	<i>Macoma ?inquinata</i>	Bent-nose macoma	<i>Macoma nasuta</i>
Alaska razor clam*	<i>Siliqua alta</i>	Pacific razor clam	<i>Siliqua patula</i>
Arctic surf clam	<i>Mactromeris polynyma</i>	Gaper clam*	<i>Tresus sp.</i>
Softshell clam	<i>Mya arenaria</i>	False softshell clam	<i>Mya pseudoarenaria</i>
Truncate softshell	<i>Mya truncata</i>	Arctic hiatella	<i>Hiatella arctica</i>

* Species observed only in excavation samples or extraliminally.

** Small species observed only in core samples.

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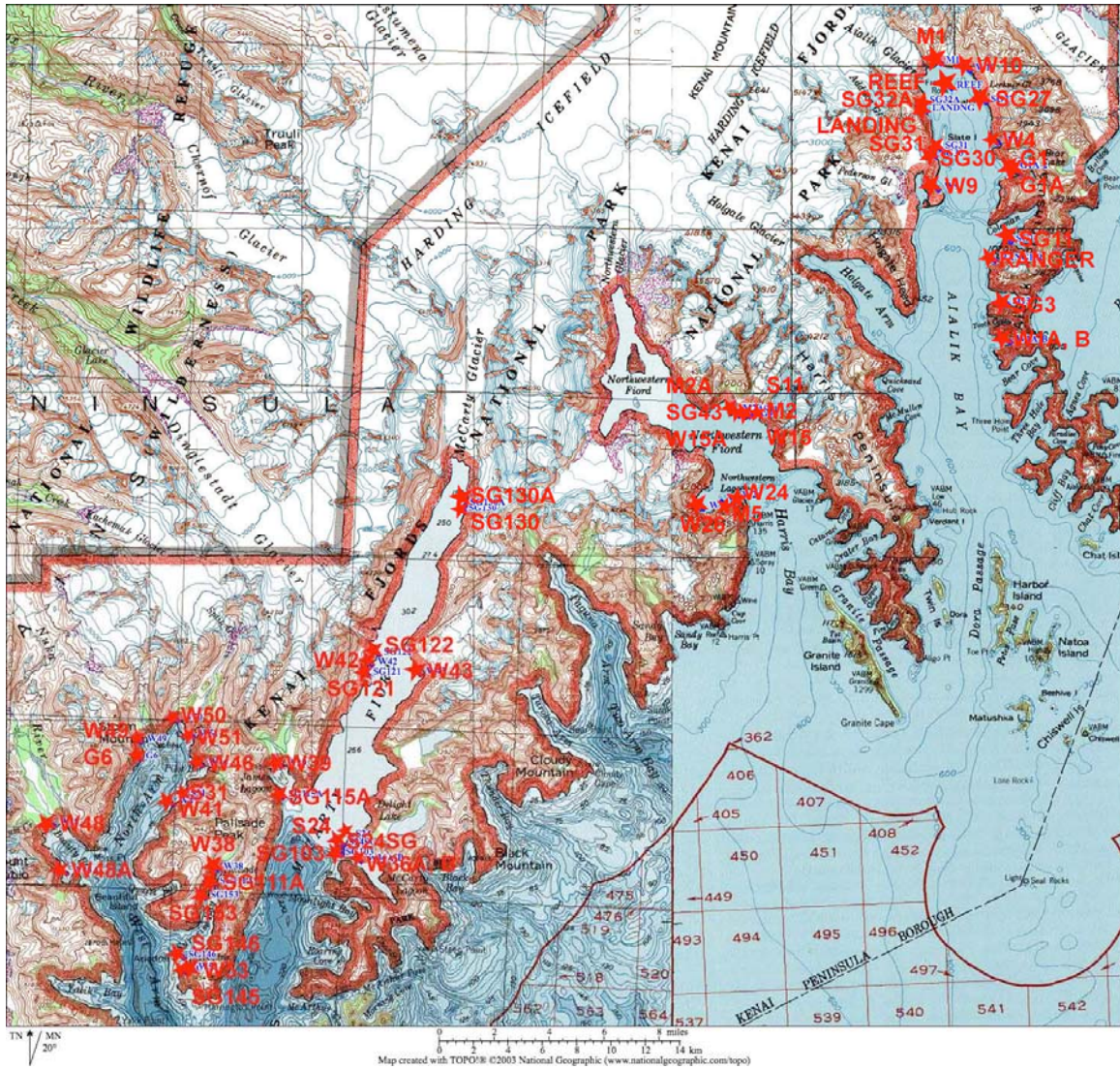


Figure 3. Locations of sites visited in KEFJ during an early June 2004 intertidal reconnaissance survey.

Comparison of Water Temperature and Salinity

We measured temperature and salinity in surface in interstitial waters at numerous sites in all three parks (Table 2). Temperatures and salinities varied considerably within and among the parks but the sampling period appears to be an overriding component for temperature. Lowest temperatures were observed in KEFJ, which was sampled a few weeks earlier than the other two parks. The elevated temperatures in some areas are likely the result of measuring in isolated standing pools after hours of insolation at high-elevation sites. The lower salinities in both surface and interstitial waters occurred where we took measurements near freshwater creeks at some sites. The role of geographic and interannual difference cannot be determined from these data.

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Figure 4. Locations of sites visited in LACL during the June 2004 intertidal reconnaissance survey.

Salinity of interstitial waters was generally slightly higher and less variable than in surface water. Sites where low salinities were observed in both surface and interstitial water were generally near a stream or river. In such locations, interstitial salinity was often substantially lower than that of the surface waters, indicating that the freshwater source was flowing as groundwater as well as on the surface. Generally, bivalves were absent in the sediments in these locations.

Map created with TOPONIS ©2003 National Geographic (www.nationalgeographic.com/topon)

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Table 2. Summary of surface and interstitial water temperature and salinities during summer surveys on beaches in LACL, KEFJ, and KATM.

Park/Region	Surface Water Temperature (°C)	Interstitial Water Temperature (°C)	Surface Water Salinity (ppt)	Interstitial Water Salinity (ppt)
Kenai Fjords National Park (Early June 2004)				
North Arm, Nuka Bay				
Average	7.4		17.3	
Std. Deviation	1.5		9.3	
Maximum	10.5		28.7	
Minimum	5.0		1.9	
McCarty Fjord				
Average	7.0		22.5	
Std. Deviation	1.3		5.6	
Maximum	9.0		29.4	
Minimum	3.5		11.5	
Northwestern Fjord				
Average	7.6		21.2	16.4
Std. Deviation	1.6		4.0	14.0
Maximum	9.5		27.2	25.6
Minimum	4.6		16.5	0.3
Aialik Bay				
Average	8.8		21.6	
Std. Deviation	1.5		5.2	
Maximum	10.7		26.8	
Minimum	5.9		10.0	
Lake Clark National Park and Preserve (Late June 2004)				
Average	10.4	11.6	15.9	20.2
Std. Deviation	2.2	0.9	10.8	7.8
Maximum	13.4	13.0	27.2	27.1
Minimum	5.7	10.3	0.6	5.8
Katmai National Park and Preserve (Late June 2005)				
Southern Region				
Average	10.9	10.8	23.9	25.2
Std. Deviation	1.6	1.3	7.1	5.3
Maximum	13.6	13.3	30.5	30.2
Minimum	8.6	9.4	8.2	15.3

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Park/Region	Surface Water Temperature (°C)	Interstitial Water Temperature (°C)	Surface Water Salinity (ppt)	Interstitial Water Salinity (ppt)
Central Region				
Average	17.1	17.3	19.3	22.1
Std. Deviation	6.3	7.3	6.3	7.0
Maximum	29.2	28.1	27.2	27.3
Minimum	12.4	11.8	11.7	12.2
Northern Region				
K40	13.2	13.3	27.5	26.3

Comparison of Sediment Characteristics

As indicated above, the parks differed considerably in topography and geology. Details for sediment texture and grain size, and organics are included in Appendix D. Sediments were generally substantially coarser in KEFJ than in the other two parks. Over 75 percent of the beaches were sandy gravel or gravelly sand (Table 3a). The average median grain size of sediments sampled in KEFJ was 2.56 mm. In contrast, only 10 percent of the beaches surveyed in KATM and none of the beaches observed in LACL were gravelly sand. Average median grain sizes in these parks were an order of magnitude smaller (0.14 and 0.48 mm, respectively). As indicated above, the topographic characteristics in KATM included components similar to both KEFJ and LACL. Beaches in both regions were dominated by sand (Table 3a). However, LACL had considerably more sandy silt and finer beaches. Silt/clay content in the sediments exceeded 20 percent at only eleven sites overall. The fine fractions dominated sediments in LACL whereas they were of minimal importance in the other parks (Appendix D).

The sources of organic components in the sediments differ considerably among the regions and, as a consequence, sediment organics also varied considerably. Based on an evaluation of the C:N ratios, organics in KEFJ and KATM are derived from both terrestrial detritus and marine phytoplankton and macrophyte sources. The importance of these sources varies with each beach's proximity to freshwater drainages and the Gulf of Alaska. Terrestrial debris gains importance with increasing proximity to freshwater outflows. LACL is relatively distant from the Gulf of Alaska and other sources of marine plants but strongly influenced by the freshwater flowing from several major river systems. Consequently, the predominant source of organics in that region is terrestrial detrital matter. In contrast, the freshwater drainages in KEFJ and KATM are relatively close to the Gulf of Alaska or related bodies of water. Consequently, sites in any embayment can represent a strong gradient in the nature of the dominant organics, with sites at the head of a bay dominated by terrestrial matter and sites at the entrance to these bays characterized by organics of marine origin.

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Table 3. Summary of sediment descriptions and sediment texture and organic characteristics at sampling locations in LACL, KEFJ, and KATM in summer 2004 and 2005. Numbers represent number or percent of of beaches

Table 3a. Sediment Texture Characteristics

Park/ Region	Gravel	Sandy Gravel	Gravelly Sand	Sand	Silty Sand	Sandy Silt	Clayey Silt	Clay	Average Median Grain Size (mm)
Kenai Fjords National Park & Preserve									
North & West Arms, Nuka Bay		6	4	1	1				2.64
McCarty Fjord		4	4			1	1		4.71
Northwestern Fjord		1	3	3					0.59
Aialik Bay	1	8	4						2.30
Overall Average	2%	45%	36%	10%	2%	2%	2%	0%	2.56
Lake Clark National Park									
Overall Average	0%	0%	0%	56%	11%	22%	11%	0%	0.14
Katmai National Park & Preserve									
Southern			1	8	1				0.58
Central			1	8	3			1	0.61
Northern			1	4	1	1			0.24
Overall Average		0%	10%	67%	17%	3%	0%	3%	0.48

Table 3b. Organic Characteristics

Park/ Region	TOC (%)	TKN (mg/Kg)	C:N Ratio
Kenai Fjords National Park			
North & West Arms, Nuka Bay	0.65	484	18.2
McCarty Fjord	0.44	523	12.75
Northwestern Fjord	0.25	565	4.69
Aialik Bay	0.62	828	12.35
Overall Average	0.49	600	12.00
Lake Clark National Park			
	0.19	348	5.5

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Park/ Region	TOC (%)	TKN (mg/Kg)	C:N Ratio
Katmai National Park & Preserve			
		TN* (%)	
Southern	0.27	0.03	10
Central	0.09	0.01	8.5
Northern	0.61	0.05	12.2
Overall Average	0.32	0.03	10.23

* TN represents total nitrogen rather than TKN. Multiplying TN values by 10000 provides approximate equivalence with TKN values.

Concentrations of TOC were considerably higher in the regions bordering the Gulf of Alaska. Unfortunately, nitrogen was not measured by the same method in all regions and a comparison is not justified. Where a similar method was employed, TKN was also higher at KEFJ, near the Gulf of Alaska, than at LACL, which is distant from the Gulf.

In all cases, concentrations of organics are relatively low compared to sediments in Prince William Sound or in nearshore subtidal sediments. In those sediments, it is common to see TOC concentrations near 1 percent (Lees and Driskell, in prep.) The implication here is that concentrations of organics in the water column, which are a principal source of nutrition for suspension-feeding bivalves, are relatively low. Moreover, they are lowest in the beaches in LACL.

Bivalve Assemblages

Bivalve assemblages were sampled by two methods to examine different aspects of their ecology. To sample the less abundant, long-lived adults of the populations, we excavated three 0.25-m² replicates at sampled sites. With these samples, we examined both epifaunal (mussels) and infaunal bivalves. We refer to these as macrobivalve assemblages. To sample the more abundant, shorter-lived species and the juveniles of the longer-lived species, we sampled a much smaller area using three 0.0081-m² cores. In these samples, we were sampling small animals that live in the sediments and are therefore referring to these collections in microinfaunal assemblages. For each component of the assemblage, we will discuss its numerical characteristics (numbers of species [S], numbers of individuals [N], the Simpson diversity index [1-D], the Shannon-Wiener diversity index [H']), species composition, and community structure. The Simpson index emphasizes the effect of the common species on diversity whereas the Shannon-Wiener index places emphasis on the effect of rare species.

Macrofaunal Bivalves in Excavation Samples

The abundance data from the excavation-sampling program are summarized in Appendix E. During the surveys in the three parks, we identified 11,157 specimens distributed among thirty taxa (i.e., species or less well defined taxonomic categories; Table 4).

Comparison of Assemblage Numerical Characteristics. The numerical characteristics exhibited strong quantitative differences among the bivalves in the macrofaunal assemblages in the parks (Table 4). KEFJ generally had substantially richer bivalve assemblages than the other parks. LACL was quite impoverished compared to the other two parks. In terms of total number of species observed in the parks, 21 taxa were observed in excavation samples in KEFJ whereas 13 were observed in KATM and only 3 in LACL. Average numbers of specimens per site ranged from 300.7 at KEFJ to only 93.0 at KATM and 79.8 at LACL. Average numbers of individuals per taxon (species) ranged from 444.0 at KEFJ, falling to 119.7 and 74.4 at LACL and KATM, respectively.

These averages were driven by several abundant species in the various parks. The dramatic differences in average specimens per site and taxon are a result of the greater importance of mussel beds in KEFJ. By park, dominant species included the foolish mussel, Baltic macoma, Arctic hiatella, and littleneck and butter clams at KEFJ, Baltic macoma and oval macoma at KATM, and Baltic macoma at LACL (Appendix E). Average number of species per site was relatively low in all parks, ranging from 3.7 in KEFJ to 3.6 and 1.4 species per site at KATM and LACL, respectively (Table 4).

Table 4. Numerical characteristics for macrofaunal bivalve assemblages collected in excavation samples during intertidal reconnaissance surveys in KEFJ, LACL, and KATM in June 2004-2005.

Park/ Site Name	Grand Total	Average No. per Taxon	Number of Taxa	Species Diversity (Simpson)	Species Diversity (H')
Katmai National Park & Preserve					
Southern Region					
KATM - K12	24	0.80	2	0.00	0.41
KATM - K8	13	0.45	3	0.60	1.30
KATM - K10	59	2.11	4	0.41	1.15
KATM - K18	6	0.21	3	0.73	1.46
KATM - K19	8	0.27	5	0.86	2.16
KATM - K21	58	2.00	3	0.27	0.70
KATM - K22	119	3.97	4	0.40	1.05
KATM - KC	72	2.40	5	0.60	1.58
KATM - DC	661	22.03	7	0.07	0.26
KATM - K28	2	0.07	2	0.00	1.00
Central Region					
KATM - K30	2	0.07	2	1.00	1.00
KATM - K31	92	3.07	3	0.51	1.07
KATM - K32A	EL*	—	—	—	—
KATM - K32B	EL	—	—	—	—
KATM - K32C	EL	—	—	—	—

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Park/ Site Name	Grand Total	Average No. per Taxon	Number of Taxa	Species Diversity (Simpson)	Species Diversity (H')
KATM - K34	EL	—	—	—	—
KATM - K34B	EL	—	—	—	—
KATM - K34C	EL	—	—	—	—
KATM - K35A	EL	—	—	—	—
KATM - K35B	EL	—	—	—	—
KATM - K35C	EL	—	—	—	—
Northern Region					
KATM - K36A	EL	—	—	—	—
KATM - K36B	EL	—	—	—	—
KATM - K36C	EL	—	—	—	—
KATM - K37	EL	—	—	—	—
KATM - K39	EL	—	—	—	—
Total	1116	85.85	13	0.46	1.44
Park Average	93.0	3.12	3.58	0.45	1.10
Std. Deviation	183.1	6.1	1.5	0.3	0.5
Kenai Fjords National Park					
North and West Arms, Nuka Bay					
KEFJ - W50	20	0.67	2	0.34	0.72
KEFJ - W49	1203	40.10	3	0.36	0.80
KEFJ - W51	236	7.87	5	0.31	0.94
KEFJ - W46	29	0.97	3	0.35	0.87
KEFJ - W47	168	5.60	1	0.00	0.00
KEFJ - W38	4	0.13	2	0.50	0.81
KEFJ - W48A	162	5.40	2	0.30	0.68
KEFJ - SG111A	122	4.07	5	0.52	1.45
KEFJ - SG153	45	1.50	3	0.50	1.08
KEFJ - SG146	EL	0.00	0	—	—
KEFJ - W53	2	0.07	2	1.00	1.00
KEFJ - SG145	53	1.77	5	0.34	1.03
McCarty Fjord					
KEFJ - SG122	1999	66.63	4	0.00	0.02
KEFJ - W42	73	2.43	8	0.74	2.30
KEFJ - SG121	430	14.33	7	0.34	1.01
KEFJ - W39	515	17.17	3	0.02	0.10
KEFJ - SG115A	1583	52.77	2	0.02	0.08
KEFJ - S24-SG	14	0.47	2	0.26	0.59
KEFJ - W36A	1717	57.23	6	0.03	0.13
KEFJ - W36B	280	9.33	11	0.70	2.02

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Park/ Site Name	Grand Total	Average No. per Taxon	Number of Taxa	Species Diversity (Simpson)	Species Diversity (H')
Northwestern Fjord					
KEFJ - M2A	6	0.20	1	0.00	0.00
KEFJ - SG43	23	0.77	1	0.00	0.00
KEFJ - M2	52	1.73	4	0.63	1.54
KEFJ - W15	EL	0.00	0	—	—
KEFJ - M5	239	7.97	5	0.41	1.24
KEFJ - W26	22	0.73	4	0.65	1.56
Aialik Bay					
KEFJ - W10	EL	0.00	0	—	—
KEFJ - SG31	16	0.53	2	0.13	0.34
KEFJ - SG30	14	0.47	4	0.67	1.59
KEFJ - G1	32	1.07	4	0.33	0.93
KEFJ - G1A	93	3.10	8	0.76	2.32
KEFJ - W9	2	0.07	2	1.00	1.00
KEFJ - S11	154	5.13	9	0.79	2.61
KEFJ - SG3	15	0.50	4	0.54	1.38
Total	9323	443.95	21	0.46	1.47
Park Average	300.7	9.14	3.7	0.40	0.97
Std. Deviation	543.2	17.5	2.6	0.3	0.7
Lake Clark National Park & Preserve					
LACL - S21	3	0.10	1	0.00	0.00
LACL - W22	220	7.33	2	0.04	0.16
LACL - S10	2	0.07	1	0.00	0.00
LACL - W8A	23	0.77	2	0.24	0.56
LACL - S8	363	12.10	2	0.03	0.12
LACL - M7	1	0.03	1	0.00	0.00
LACL - SG2	1	0.03	1	0.00	0.00
LACL - SG1	9	0.30	2	0.22	0.50
LACL - W1	96	3.20	1	0.00	0.00
Total	718	119.67	3	0.06	0.22
Park Average	79.8	2.66	1.4	0.06	0.15
Std. Deviation	128.8	4.3	0.5	0.1	0.2
Grand Total	11157	6.77	30	0.36	0.86

* EL = Extralimital species observed

Values of both Simpson and Shannon-Wiener species diversity were generally similar at KEFJ and KATM but far lower at LACL (Table 4). The average

Simpson index (driven by common species) was slightly higher for KATM sites (0.45) than at KEFJ (0.40) but far lower at LACL (0.06). When all sites in a park were combined, KATM and KEFJ were equal (0.46) but LACL remained the same (0.06). For the Shannon-Wiener index, driven by rarer species, the patterns are similar. Again, the average index was slightly higher at KATM (1.10) than at KEFJ (0.97) but LACL was much lower (0.15). For the combined sites from the parks, again, KATM and KEFJ were nearly equal (1.44 and 1.47, respectively) whereas LACL was much lower (0.22).

Comparison of Species Composition. To compare species composition patterns, we have limited our consideration to macrobivalve species that dominated in the excavation samples in at least one park or that were important but observed extralimittally (Table 5).

The dominant species comprise at least 99 percent of the total number observed in all parks, indicating that the species omitted from this list, overall, were quite rare at all sites and parks.

It is clear from these data that the macrofaunal bivalve faunae varied considerably on the beaches in the three parks. The bivalve fauna was strongly dominated by only one or two species in each park. Baltic and oval macomas dominated (87 percent) in KATM, whereas foolish mussels and Baltic macomas dominated (85 percent) in KEFJ, and Baltic macomas dominated (96.9 percent) in LACL. Baltic macomas were one of the principal dominants in all parks. Only Baltic macomas and softshell clams dominated in all three parks but their relative importance varied considerably among the parks.

Overall, only three species (foolish mussels, Baltic macomas, and Arctic hiatellas) contributed more than 5 percent of the individuals observed. Foolish mussels were the numerical dominant but only because mussel beds were well developed on soft beaches in many areas in KEFJ. In contrast, mussel beds were generally poorly developed on soft beaches in KATM and were absent on the beaches surveyed in LACL¹.

In terms of frequency of occurrence, 56, 45, and 100 percent of the dominant species occurred in at least one-third of the sites sampled in KATM, KEFJ, and LACL, respectively. This suggests a moderate degree of dissimilarity among the macrofaunal bivalves at sites within the parks. Based on the habitat and substrate differences and the extralimittal observations, this interpretation seems accurate although greater replication at each site might add helpful detail for rarer species.

Several species were restricted to a single park. This included northern horsemussels (KEFJ), Alaska razor clams (KATM), and Arctic hiatella (KEFJ).

¹ Small areas with loosely developed mussel beds have been observed at several locations in LACL, e.g., at the north end of Chisik Island and on the protected side of Gull Island in Chinitna Bay, but are not common (Lees and Driskell, in preparation).

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While Pacific razor clams were commonly observed in LACL, they were rare in KATM where they were apparently replaced by Alaska razor clams. The latter was not observed in LACL.

Table 5. Species that dominated in at least one park in macrofaunal bivalve assemblages collected in excavation samples during intertidal reconnaissance surveys in KEFJ, LACL, and KATM in 2004-2005.

Species	KATM			KEFJ			LACL			Overall		
	Total Number Observed	Frequency of Occurrence	Relative Abundance	Total Number Observed	Frequency of Occurrence	Relative Abundance	Total Number Observed	Frequency of Occurrence	Relative Abundance	Total Number Observed	Frequency of Occurrence	Relative Abundance
Northern horsemussel	–	–	–	23	3	0.2	–	–	–	23	3	0.2
Foolish mussel	2	7	0.2	6670	24	71.5	–	–	–	6672	31	59.8
Basket cockle	38	5	3.4	22	5	0.2	–	–	–	60	10	0.5
Alaska razor clam	3	6	0.3	–	–	–	–	–	–	3	6	0.0
Pacific razor clam	–	1	–	–	–	–	6	4	0.8	6	5	0.1
Baltic macoma	796	14	71.3	1247	20	13.4	696	5	96.9	2739	39	24.5
Oval macoma	178	8	15.9	103	10	1.1	–	–	–	281	18	2.5
Pointed macoma	2	2	0.2	38	3	0.4	–	–	–	40	5	0.4
Littleneck clam	–	3	–	146	13	1.6	–	–	–	146	16	1.3
Butter clam	16	6	1.4	192	9	2.1	–	–	–	208	15	1.9
Softshell clam	61	10	5.5	5	2	0.1	16	4	2.2	82	16	0.7
False softshell clam	10	4	0.9	7	4	0.1	–	–	–	17	8	0.2
Arctic hiatella	–	–	–	813	14	8.7	–	–	–	813	14	7.3
Grand Total	1116		99.1	9323		99.4	718		100	11157		99.4

We must emphasize that the dominance patterns indicated by the data in Table 5 are based on numbers of individuals, which do not completely reflect the importance of a few large species that occur at low densities but form extensive

beds in some areas. The densities of these species are too low to produce high numbers in three excavation samples compared to small abundant clams like the foolish mussel and Baltic macoma, but their size makes them important. For example, species such as Pacific razor clams are important to commercial and sport fishermen in LACL. Moreover, softshell and false softshell clams form extensive beds on mud flats in LACL and KATM. Also, Arctic surf clams are common on many sand beaches in LACL and KATM. Littleneck and butter clams are common in many mixed-soft beaches exposed to strong tidal currents in KEFJ and KATM. Besides human use, brown bears and/or sea otters exploit all of these species where their ranges overlap. In contrast, sea otters and diving ducks are the primary predators for foolish mussels while diving ducks, shorebirds, and flatfish are major vertebrate predators on Baltic macomas.

Community Structure. The species abundance data were subjected to cluster analysis to provide insight into relationships among species and sites. Not included in the analysis were sites lacking quantitative measures of abundance and taxa 1) lacking a species designation, 2) found at only one station, or 3) found only as single individuals. However, in a few instances, these species or sites were included because they provided valuable insight into groupings in a park (e.g., Pacific razor clams in LACL).

Following the clustering results, the matrix of species and sites was arranged in the order indicated by their respective dendrograms (Table 6; the underlying dendrograms are included in Appendix G) with the cluster groups demarcated by heavier borders. Patterns of abundance within the cluster groups (sections bordered by dark lines) indicate species that determine the site clustering.

Site Relationships. Cluster analysis broke the 52 sites into eight different groups, most characterized by relatively unique combinations of species groups (Table 6; Appendix G-1). The first group, comprising mostly sites from KEFJ, was primarily characterized by a combination of foolish mussels and Baltic macomas. Generally, these nine sites had very high abundance but moderate species richness. The second group, a mixture of sites from LACL and KATM, was dominated by a combination of Baltic macomas and softshell clams. The six sites had moderate abundance and moderately low species richness. The third group, a mixture of sites from KEFJ and LACL, was dominated by Baltic macoma. These four sites had very low abundance and species richness. The fourth group, comprising mainly sites from KATM, was driven by a relatively loose group of five species (Baltic and oval macomas, butter and false softshell clams, and basket cockles). These eight sites had low abundance but very high species richness. The fifth group, including only sites from KEFJ, was also driven largely by a relatively tight group of five species with moderate to high abundance. The major species included foolish mussels, littleneck and butter clams, Arctic hiatella, and Baltic macomas. These thirteen sites had high abundance and very high species richness. The sixth and seventh groups showed no strong relationships. Finally, Pacific razor clams drove the eighth

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Table 6. Species/site matrix for macrofaunal bivalve assemblages collected in excavation samples during intertidal reconnaissance surveys in KEFJ, LACL, and KATM in 2004-2005. Numbers represent total individuals per site.

Park/ Station	Northern horsemussel	Foolish mussel	Littleneck clam	Arctic hiatella	Baltic macoma	Butter clam	Basket cockle	Oval macoma	False softshell clam	Truncate softshell	Softshell clam	Rough diptodon	Pointed macoma	Alaska razor clam	Salmon tellin	Pacific razor clam	N	S
KATM - DC		2			639		7				8		2				658	5
KEFJ - SG122		1995			2		1	1									1999	4
KEFJ - SG115		1568			15												1583	2
KEFJ - W38		3			1												4	2
KEFJ - W48A		133			29												162	2
KEFJ - W50		4			16												20	2
KEFJ - W39		3			509						3						515	3
KEFJ - W46		1	5		23												29	3
KEFJ - W49		920			281								2				1203	3
KATM - K12					22						2						24	2
LACL - S8					357						6						363	2
LACL - W22					215						5						220	2
LACL - W8A					20						3						23	2
KATM - K21		EL			49			1			8						58	3
KATM - K31					49		1				42						92	3
KEFJ - M2A					6												6	1
KEFJ - SG43					23												23	1
LACL - W1					96												96	1
LACL - SG1					8											1	9	2
KATM - K10		EL			6			45	3						5		59	4
KATM - K22					22		4	90	3								119	4

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Park/ Station	Northern horsemussel	Foodish mussel	Littleneck clam	Arctic hiatella	Baltic macoma	Butter clam	Basket cockle	Oval macoma	False softshell clam	Truncate softshell	Softshell clam	Rough diplodon	Pointed macoma	Alaska razor clam	Salmon tellin	Pacific razor clam	N	S
KATM - KC					2	4	25	38	3								72	5
KEFJ - W42					3	1	13	33	2	12							64	6
KATM - K18					2	3		1									6	3
KATM - K8			EL		5	7		1									13	3
KEFJ - W9					1			1									2	2
KATM - K19							1	2						3	1		7	4
KEFJ - G1		26	4	1		1											32	4
KEFJ - SG153		16	28	1													45	3
KEFJ - SG145		5	2	43	1	2											53	5
KEFJ - W36A		1691	2	2	19	1					2						1717	6
KEFJ - SG111A	7	2	8	81	24												122	5
KEFJ - W51		3	17		195	18				3							236	5
KEFJ - M2		25		7	19				1								52	4
KEFJ - M5		10	8	181	28			12									239	5
KEFJ - W26		1		2	9			10									22	4
KEFJ - S11	6	31	7	56	9	18	5	20									152	8
KEFJ - W36B	10	1	61	85		111	1	5	3								277	8
KEFJ - SG121		43	2	345	35		2	2	1								430	7
KEFJ - G1A		4		2		28		13		1			33				81	6
KEFJ - S24-SG		2				12											14	2
KEFJ - W47		168															168	1
KEFJ - SG31		15		1													16	2
KEFJ - SG3			1					1				10	3				15	4
KEFJ - SG30			1	6				6									13	3
KATM - K28						1			1								2	2

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Park/ Station	Northern horsemussel	Foodish mussel	Littleneck clam	Arctic hiatella	Baltic macoma	Butter clam	Basket cockle	Oval macoma	False softshell clam	Truncate softshell	Softshell clam	Rough diplodon	Pointed macoma	Alaska razor clam	Salmon tellin	Pacific razor clam	N	S
KEFJ - W53	1					1											2	2
KATM - K30			EL			1					1				EL		2	2
LACL - S10											2						2	1
LACL - M7																1	1	1
LACL - S21																3	3	1
LACL - SG2																1	1	1
Frequency of Occurrence	4	25	13	14	35	15	10	18	8	3	11	1	4	1	2	4		
Total Abundance	28	6697	159	827	2775	224	70	300	25	19	93	11	44	4	8	10		

group, comprising only three sites from LACL. It had extremely low abundance and very low species richness.

Generally, the site groups comprised sites mainly from a single park. Three large groups comprised solely KEFJ sites, probably reflecting that sediments in KEFJ were substantially coarser than those in KATM and LACL. One site, where Pacific razor clams dominated, comprised solely LACL sites. Both KATM and LACL sites mixed in groups with KEFJ sites.

Species Relationships. Cluster analysis for species produced seven somewhat poorly defined species groups (Table 6; Appendix G-2). This analysis suffered because we intentionally retained several important species with restricted distribution and low abundance (e.g., truncate softshell, Alaska, and Pacific razor clams, rough dipodon, and salmon tellin) in order to demonstrate the distinctiveness of several sites, especially those in LACL. Elimination of these uncommon species would have eliminated those sites from the cluster analysis for sites and the unique nature of the bivalve fauna in LACL would have been overlooked.

Four “groups” comprised only a single species. In the cases of Alaska and Pacific razor clams populations on exposed sand beaches in KATM and LACL, this accurately reflects that these species were not closely associated with any other species. In the case of Baltic macomas and butter clams, the significance of this division is not clear.

The supergroup comprising groups 2 through 5 seems relatively coherent. The strongest of the groups comprises species found almost exclusively in KEFJ (foolish mussels, littleneck clams, and Arctic hiatella). The other groups include species that are well represented in both KEFJ and KATM.

Microinfaunal Bivalves in Core Samples

The abundance data from the core-sampling program are summarized in Appendix F. During the surveys in the three parks, we identified 1,310 specimens distributed among thirty taxa (Table 7).

Comparison of Assemblage Characteristics. As was observed in macrofaunal bivalves, strong quantitative differences were observed among the parks (Table 7). KEFJ generally had higher average numbers of individuals (40.5) and individuals per species (1.3) than KATM (22.1 and 0.7, respectively) but the total (19 in KEFJ and 18 in KATM) and average numbers (3.5 in each) of species was very similar in the two parks. In contrast, quantitative measures were much lower for the microinfaunal bivalves in LACL, where average numbers of individuals (3.7) and species (0.09) per site, and total and average numbers of taxa (4 and 1.0, respectively) were far lower than in the other parks. This is likely partly a reflection of the environmental limitations imposed by the combined effects of high concentrations of suspended solids, low salinity, poor nutrient

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conditions, extreme tidal currents, and ice scour that characterize Cook Inlet adjacent to LACL.

Table 7. Numerical characteristics for microinfaunal bivalve assemblages collected in excavation samples during intertidal reconnaissance surveys in KEFJ, LACL, and KATM in June 2004-2005.

Park/ Station	Grand Total	Average No. per Taxon	Number of Taxa	Species Diversity (Simpson)	Species Diversity (H')
Katmai National Park & Preserve					
Southern Region					
KATM - K12	6	0.20	2	0.33	0.65
KATM - K10	14	0.47	5	0.80	2.12
KATM - K18	1	0.03	1	0.00	0.00
KATM - K19	4	0.13	2	0.67	1.00
KATM - K21	21	0.70	4	0.35	0.99
KATM - K22	53	1.77	6	0.69	2.05
KATM - KC	4	0.13	4	1.00	2.00
KATM - DC	139	4.63	6	0.58	1.49
KATM - K28	8	0.27	5	0.86	2.16
Central Region					
KATM - K30	1	0.03	1	0.00	0.00
KATM - K31	7	0.23	4	0.81	1.84
KATM - K37	7	0.23	2	0.57	0.99
Total	265	14.72	18	0.79	2.86
Park Average	27.8	0.9	3.9	0.6	1.4
Std. Deviation	44.7	1.5	1.8	0.3	0.8
Kenai Fjords National Park					
North and West Arms, Nuka Bay					
KEFJ - W50	2	0.07	2	1.00	1.00
KEFJ - W49	96	3.20	2	0.37	0.79
KEFJ - W51	127	4.23	8	0.64	1.90
KEFJ - W46	17	0.57	5	0.74	2.00
KEFJ - W38	2	0.07	1	0.00	0.00
KEFJ - W48A	18	0.60	2	0.11	0.31
KEFJ - SG153	10	0.33	2	0.20	0.47
KEFJ - SG146	2	0.07	2	1.00	1.00
McCarty Fjord					
KEFJ - SG122	12	0.40	4	0.45	1.21
KEFJ - W42	93	3.10	7	0.24	0.84
KEFJ - SG121	34	1.13	3	0.57	1.31

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Park/ Station	Grand Total	Average No. per Taxon	Number of Taxa	Species Diversity (Simpson)	Species Diversity (H')
KEFJ - W39	40	1.33	2	0.05	0.17
KEFJ - SG115A	127	4.23	5	0.08	0.32
KEFJ - S24-SG	4	0.13	3	0.83	1.50
KEFJ - W36A	90	3.00	6	0.17	0.62
KEFJ - W36B	46	1.53	8	0.63	1.95
Northwestern Fjord					
KEFJ - M2A	4	0.13	2	0.50	0.81
KEFJ - SG43	2	0.07	1	0.00	0.00
KEFJ - S11	12	0.40	5	0.73	1.90
KEFJ - M2	21	0.70	3	0.27	0.72
KEFJ - M5	19	0.63	4	0.71	1.78
KEFJ - W26	14	0.47	4	0.66	1.57
Aialik Bay					
KEFJ - SG31	129	4.30	2	0.02	0.07
KEFJ - G1	88	2.93	2	0.02	0.09
KEFJ - W9	3	0.10	2	0.67	0.92
Total	1012	53.26	19	0.64	2.22
Park Average	40.5	1.3	3.5	0.4	0.9
Std. Deviation	45.0	1.5	2.1	0.3	0.7
Lake Clark National Park & Preserve					
LACL - S21	0	0.00	0	—	—
LACL - W22	10	0.33	1	0.00	0.00
LACL - W8A	3	0.10	1	0.00	0.00
LACL - S8	6	0.20	2	0.53	0.92
LACL - M7	0	0.00	0	—	—
LACL - SG1	0	0.00	0	—	—
LACL - M2	1	0.03	1	0.00	0.00
LACL - SG2	8	0.27	3	0.46	1.06
LACL - W1	5	0.17	1	0.00	0.00
Total	33	1.10	4	0.23	0.72
Park Average	3.7	0.09	1.0	0.16	0.35
Std. Deviation	3.8	0.1	1.0	0.3	0.5
Grand Total	1310	1.02	3.1	0.44	0.99

Largely different species drove these averages in the three parks. In KEFJ, the three most abundant species were foolish mussels, robust mysellas, and silky axinopsids. The two latter species are very small (adults <10 mm in length). In KATM, the top three were minute turtos, foolish mussels, and Baltic macomas.

Again two are relatively small species. Baltic macomas were the only abundant species in microinfaunal samples from LACL.

Values of both Simpson and Shannon-Wiener species diversity were slightly higher at KATM than at KEFJ but far lower at LACL (Table 7). The average Simpson index (driven by common species) was slightly higher for KATM sites (0.56) than at KEFJ (0.40) but far lower at LACL (0.16). When all sites in a park are combined, KATM was again higher than KEFJ (0.79 vs. 0.64) and LACL remains much lower (0.23). For the Shannon-Wiener index, driven by rarer species, the patterns are similar. Again, the average index was slightly higher at KATM (1.27) than at KEFJ (0.90) but LACL is much lower (0.35). For the combined sites from the parks, KATM is, again, higher than KEFJ (2.86 vs. 2.22, respectively) whereas LACL is much lower (0.72).

Comparison of Species Composition. As with the macrofaunal bivalves, we have limited our consideration to microinfaunal species that dominated in the core samples in at least one park when comparing species composition patterns (Table 8). The dominant species comprise over 90 percent of the total number observed in all parks and clearly represent the species exerting the greater influence numerically. However, four of the species have maximum sizes of less than about 15 mm and so clearly do not exert a great influence on biomass or ecological function.

The dominance patterns varied considerably among the parks. Two species, foolish mussels and minute turtons, dominated abundance in KATM and were the only species that contributed more than 15 percent to total numbers. In both KEFJ and LACL, only one species, foolish mussels and Baltic macomas, respectively, contributed more than 15 percent. Baltic macomas were the only species that were a dominant in all three parks. The foolish mussel was the only species that dominated in two parks. Three species, silky axinopsid, pointed macoma, and Arctic hiatella, were restricted to KEFJ.

Overall, five species contributed more than 5 percent of the individuals observed but none contributed more than 50 percent. As in the macrofauna, the most abundant bivalve was the foolish mussel (48 percent) but in this case, the specimens were predominantly juveniles. The other four species were robust mysella (11.2 percent), Baltic macoma (10.7 percent), minute turton (7.7 percent), and silky axinopsid (7.5 percent). All are small species and, with the exception of the Baltic macoma, probably exert little influence on the community and contribute little to large vertebrate predators in the parks.

In terms of frequency of occurrence, 38, 40, and 33 percent of the dominant species occurred in at least one-third of the sites sampled in KATM, KEFJ, and LACL, respectively. This suggests strong dissimilarity among the microinfaunal bivalve assemblages at the sites within the parks. However, another possible interpretation is that the level of replication at each site was insufficient to provide a clear representation of the bivalve fauna.

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Table 8. Species that dominated in at least one park in microinfaunal bivalve assemblages collected in core samples during intertidal reconnaissance surveys in KEFJ, LACL, and KATM in 2004-2005.

Species	KATM			KEFJ			LACL			Overall		
	Total Number Observed	Frequency of Occurrence	Relative Abundance	Total Number Observed	Frequency of Occurrence	Relative Abundance	Total Number Observed	Frequency of Occurrence	Relative Abundance	Total Number Observed	Frequency of Occurrence	Relative Abundance
Foolish mussel	54	4	20.4	575	19	56.8	–	–	–	629	23	48.0
Silky axinopsid	–	–	–	98	5	9.7	–	–	–	98	5	7.5
Robust myrella	27	1	10.2	120	9	11.9	–	–	–	147	10	11.2
Baltic macoma	31	8	11.7	80	11	7.9	29	6	87.9	140	25	10.7
Oval macoma	15	4	5.7	5	3	0.5	–	–	–	20	7	1.5
Pointed macoma	–	–	–	24	3	2.4	–	–	–	24	3	1.8
Littleneck clam	2	2	0.8	5	3	0.5	–	–	–	7	5	0.5
Butter clam	7	3	2.6	5	3	0.5	–	–	–	12	6	0.9
Softshell clam	8	3	3.0	–	–	–	2	1	6.1	10	4	0.8
Arctic hiatella	–	–	–	58	12	5.7	–	–	–	58	12	4.4
Minute turton	98	3	37.0	3	1	0.3	–	–	–	101	4	7.7
Grand Total	265		92.1	1012		98.4	33		93.9	1310		97.0

Community Structure. Table 9 was prepared in the manner described above for Table 6. The underlying dendrograms are included in Appendix G. Because the numbers of individuals in the microbivalve samples was an order of magnitude lower than in the macrobivalve samples but the numbers of sites and species is similar, the site/species matrix is necessarily more sparsely populated.

Site Relationships. Cluster analysis segregated the 41 sites into two major groups, each of which split into several smaller groups. The most important

major grouping, characterized by presence of Baltic macomas, includes the upper seven groups in Table 9 (see Appendix G-3). Baltic macomas dominate nearly all of the subgroups in the major subgrouping. In the first group, Baltic macomas share dominance with softshell clams. The four sites in this group, mostly from KATM, had moderate abundance and species richness. In the second group, including most of the LACL sites, Baltic macomas are the sole species. These seven sites had moderate abundance but very low species richness. Group 3, from KEFJ, adds silky axinopsids. These two sites had very low abundance but moderate species richness. In group 4, foolish mussels and Baltic macoma share dominance. These six sites, mostly from KEFJ, had moderate abundance and moderately low species richness. Group 5 adds Arctic hiatellas to group 4. These two KEFJ sites had moderately low abundance but moderate species richness. Group 7 is somewhat heterogeneous but the dominants are Baltic and oval macomas. These three sites had moderately low abundance but moderate species richness. Group 6, from KEFJ, with only foolish mussels, is an oddity.

Baltic macomas are lacking from the second major grouping and although four species are common in these sites, none is universal. Important species are foolish mussels, rough mysellas, Arctic hiatellas, and butter clams. Except for the mussels, the important species in the major grouping are generally lacking in the first major grouping. Littleneck and butter clams characterize group 8. These five sites, mixed from KATM and KEFJ, had moderate abundance and species richness. Like group 5, group 9 is dominated by mussels and Arctic hiatellas but lacks Baltic macomas. These three KEFJ sites had moderate abundance and species richness. Group 10 adds rough mysellas to group 9. These five KEFJ sites had moderate abundance and species richness. Finally, group 11 includes silky axinopsids, rough mysellas, Arctic hiatellas, and oval macomas. These two KEFJ sites had moderately high abundance and species richness.

In general, sites from the different parks grouped together. Six groups comprised solely KEFJ sites. Only one group comprised solely KATM sites. All LACL sites but one were included in a single group.

Species Relationships. Cluster analysis produced 4 somewhat loose species groups (Table 9; Appendix G-4). None of the relationships is strong. The strongest relationship in the first group is between foolish mussels and Baltic macomas. As indicated in the previous section, the analysis suffers from the low abundance of bivalves collected in the microinfaunal core samples. An examination of the abundance data in Table 9 indicates that the inclusion of minute turtons and softshell clams is weak. The relationship between littleneck and butter clams in group 4 is relatively strong but the number of occurrences is low. Moreover, the relationship between rough mysellas and Arctic hiatellas is relatively strong.

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Table 9. Species/site matrix for microinfaunal bivalve assemblages collected in core samples during intertidal reconnaissance surveys in KEFJ, LACL, and KATM in 2004-2005. Numbers represent total individuals per site.

Park/ Station	Foolish mussel	Baltic macoma	Minute turton	Softshell clam	Silky axinopsid	Pointed macoma	Robust mysella	Arctic hiatella	Oval macoma	Littleneck clam	Butter clam	Grand Total	Number of Taxa
KATM-DC	42	15	79	1								139	6
KATM-K31		2		3								7	4
KATM-K37		3		4								7	2
LACL-S8		4		2								6	2
KATM-K30		1										1	1
KEFJ-SG43		2										2	1
LACL-M2		1										1	1
LACL-SG2		6										8	3
LACL-W1		5										5	1
LACL-W22		10										10	1
LACL-W8A		3										3	1
KEFJ-W26	1	5			1		7					14	4
KEFJ-W50		1			1							2	2
KATM-K12	5	1										6	2
KEFJ-M2A	3	1										4	2
KEFJ-W39	1	39										40	2
KEFJ-W48A	17	1										18	2
KEFJ-W49	73	23										96	2
KEFJ-SG115A	122	1				1						127	5
KEFJ-M2	18	2						1				21	3
KEFJ-M5	5	2	3					9				19	4
KEFJ-G1	87											88	2
KEFJ-W38	2											2	1
KATM-K21		2	17						1			21	4
KATM-KC		1							1			4	4
KATM-K22	6	6	2			3	27		9			53	6
KATM-K10				2					4	1	5	14	5
KATM-K28	1									1	1	8	5
KEFJ-SG153	9									1		10	2
KEFJ-W51	1				12	22	71			3	1	127	8
KATM-K18											1	1	1
KEFJ-S11	6							1			1	12	5
KEFJ-S24-SG	2							1				4	3
KEFJ-SG31	128							1				129	2
KEFJ-SG121	12						3	19				34	3
KEFJ-SG122	1						1	9				12	4
KEFJ-W36A	82	3					1	2				90	6
KEFJ-W36B	5						27	7	1		3	46	8

INTERTIDAL BIVALVES IN SOUTHWEST ALASKA NETWORK PARKS

Park/ Station	Foolish mussel	Baltic macoma	Minute turton	Softshell clam	Silky axinopsid	Pointed macoma	Robust mysella	Arctic hiatella	Oval macoma	Littleneck clam	Butter clam	Grand Total	Number of Taxa
KEFJ-W9								2				3	2
KEFJ-W42					81	1	1	5	1	1		93	7
KEFJ-W46					3		8	1	3			17	5
Freq. of Occur	23	25	4	5	5	4	10	12	7	5	6		
Grand Total	629	150	101	10	98	24	147	58	20	7	12	1310	3.1

Band Transects and Quadrats

In areas where siphons or biogenic activities of individual organisms produced distinguishable surficial cues, we used band-transect or quadrat-sampling techniques to obtain density estimates for large clams and other large infaunal organisms or surficial indications of foraging activity by vertebrates. In some cases, data were collected on two or more entities (e.g., softshell clams and fat innkeeper worms at KATM - K37; Table 10). Because these samples can be completed so rapidly, higher power can be achieved as required with low sampling costs.

We employed a variety of dimensions (quadrat size or band width) for sampling plots during these surveys. Each size was chosen with the intent of optimizing the effort at the specific location. For softshell clams, densities measured with quadrats or band transects ranged from 0.23 to 11.4 clams/m² (Table 10). For Pacific razor clams, densities ranged from 0.35 to 2.49 clams/m².

Where we had data from both excavation samples and band transects, we compared density estimates. In all but one case, the density estimates from excavation samples were appreciably higher than those observed in the band transects. Considering that “shows” observed during visual sampling are sometimes not visible (e.g., obscured by alga or inactive clams with the opening not yet restored), and excavation sampling detects smaller animals than are comfortably identified during band-transect sampling, this difference is understandable. Overall, excavation estimates were about 50 percent higher than band-transect estimates, but the differences appeared to be considerably greater for razor clams than for softshell, butter, and littleneck clams. With razor clams, the “shows” are often obscured by water standing in the ripplemarks left in the sand as the tide receded. The implication is that band-transect sampling provides a conservative estimate of the actual density for the target species and is limited to the larger size fraction of the population. Actual densities may be at least 50 percent higher than densities measured by visual methods.

INTERTIDAL BIVALVES IN SOUTHWEST ALASKA NETWORK PARKS

Table 10. Summary for quadrat and band-transect estimates for macrofaunal density, power analysis, and number of sampling plots required to have at least a 50-percent probability of detecting a 25-percent effect with a 2-tailed test assuming $\alpha = 0.1$.

Park - Site	KATM - K21	KATM - K8	KATM - K37	KATM - K37
Sample Plot Size	0.25 sq m quad	0.25 sq m quad	0.5 m X 10' bands	0.5 m X 10' bands
Object of Sampling	Softshell Clam	Butter Clam	Softshell Clam	Innkeeper Worm
Sigma	1.21	0.74	12.20	8.19
Mean	1.26	1.63	17.39	11.94
Effect	0.32	0.41	4.35	2.99
No. of Plots Required for Design	42	11	23	22
Power	0.5	0.52	0.5	0.51
Est. Density	8.92	6.50	11.41	7.84
No. of Plots	13	8	18	18
Park - Site	KATM - K12	KATM - K12	KATM - K32	KATM - K32
Sample Plot Size	1m X 10' bands	1m X 10' bands	1m X 10' bands	2 m X 20' bands
Object of Sampling	Softshell Clam	Bear Foraging Pits	Softshell Clam	Softshell Clam
Sigma	2.56	2.32	18.37	1.69
Mean	4.90	3.50	24.50	1.38
Effect	1.23	0.88	6.13	0.34
No. of Plots Required for Design	13	20	26	66
Power	0.5	0.5	0.5	0.5
Est. Density	1.61	1.15	8.04	0.23
No. Of Plots	10	10	24	8
Park - Site	KEFJ - W46	LACL - S21	LACL - M2	LACL - SG2
Sample Plot Size	0.25 sq m quad	1m X 50' bands	1m X 200' bands	1m X 100' bands
Object of Sampling	Littleneck Clam	Pacific Razor Clam	Pacific Razor Clam	Pacific Razor Clam
Sigma	1.54	2.85	4.95	—
Mean	1.33	5.88	21.50	76.00
Effect	0.33	1.47	5.38	19.00
No. Of Plots Required for Design	60	12	4	—

Power	0.5	0.52	0.51	–
Est. Density	5.33	0.39	0.35	2.49
No. of Plots	15	8	2	1

DISCUSSION

The primary purpose of this study was to improve the understanding of intertidal resources on soft beaches in SWAN parks. A secondary objective was to provide information that could be used in designing a long-term monitoring program focused on detecting long-term change resulting from changes in natural cycles, global climate, geologic events, or anthropogenic activities. Such changes are important because they affect the types, quantity, and quality of intertidal resources on soft or unconsolidated beaches used as prey by the major migratory and resident vertebrate predators in the SWAN parks. Another important objective was to identify environmental or biological factors important in shaping community structure.

During these surveys, we found that the habitats vary substantially within and among the three parks. The sediments in each park strongly reflect the differing geologic and oceanographic forces operating therein. Generally, habitats in KEFJ were coarser than in the other two parks; various mixes of silt, sand, gravel, and cobble characterize many beaches. The coarseness of the sediments reflects both the relative youth of these beaches, the steepness of the terrain, and the glacial origin of the embayments. Retreating glaciers have bared many of these beaches only within the past few centuries or decades. Consequently, sediment conditions are in flux and, while the bivalve fauna includes numerous species, the assemblages are not well developed in many areas, especially toward the head of the fjords where sediments are organically and biologically impoverished or empty. One consequence of the coarse sediments is that mussels form extensive beds in many areas where gravel occurs above mid-intertidal levels, an elevation that provides at least a partial refuge from most marine predators. Such beds are sparse or absent in the other parks. Another consequence is that hard-shelled clam assemblages (e.g., littleneck and butter clams) generally associated with mixed-soft sediments are more common in KEFJ than in the other parks, where mixed-soft substrata are uncommon. In fact, bivalve assemblages on KEFJ beaches were dominated by the widest variety of species. In addition to mussels and hard-shelled clams, softshell clams, Baltic macomas, and Arctic hiatellas also dominated the assemblages in specific areas.

Beaches in KATM display widespread evidence of recent volcanic eruptions, effects of extreme oceanic and climatic conditions, and seismic events. Volcanic ash and pumice strongly influenced sediments on many beaches or formed thick layers of these materials buried under more recent sediments. The bivalve assemblages were dominated by fewer species, i.e., Baltic and oval macomas and softshell clams. Some species that dominated in KEFJ were either absent or sparse in KATM. In particular, the northern beaches in KATM were impoverished. Considering that appreciable numbers of clams were found only

in protected areas, especially mud flats, it is likely the severe oceanic conditions in the region play a key role in this impoverishment.

In contrast, because of the irregularity of their shorelines, the degree of exposure on the beaches varies considerably in both KEFJ and the southern region in KATM. This variability in microclimates was associated with relatively higher diversity in bivalve assemblages. However, although species composition varied widely among beaches, the numbers of species involved on any particular beach was generally low.

The variety of factors driving conditions on the beaches and in the associated bivalve assemblages appears to be more extreme in LACL than in the other parks. Important factors in LACL include:

- Strong tidal currents caused by the extreme tidal flux of Cook Inlet;
- Heavy sediment loads entering Cook Inlet from several nearby major river systems;
- High concentrations of suspended solids in the waters of upper Cook Inlet;
- Low concentrations of detrital material and phytoplankton for nutrition;
- Relatively low salinity;
- Ice scour;
- Strong wind-driven wave action; and
- Uplift by the 1964 earthquake.

As a consequence, diversity of habitat and the bivalve assemblages is low. The main productive habitats are extensive sand flats on the exposed shores of LACL and extensive mud flats inside the two protected embayments. Where distant from freshwater outflow from rivers, both habitats support robust populations of one or two of the only three species that appear to thrive in this rigorous environment. Pacific razor clams, abundant on some sand beaches below the northern boundary of LACL, are commercially harvested at Polly Creek. Softshell clams and Baltic macomas are abundant on several mud flats in Tuxedni and Chinitna Bays, primarily in areas where the freshwater runoff becomes diluted with saltier water from Cook Inlet.

It is likely that predators play an important role in determining the density and size structure of several intertidal macrobivalve species observed in the excavation samples on many beaches. Sea otters forage on littleneck and butter clams, Arctic surfclams, and probably softshell clams in KEFJ and KATM. Brown bears forage on razor and softshell clams in KATM. In the case of razor, littleneck, butter, softshell, and surf clams, densities observed on the beaches are generally sufficiently low that focused predation could affect density and size structure. For

example, we observed a small isolated area at Swikshak Beach in KATM (~200 X 30 m) in which a brown bear had made 59 serious (generally successful) digs for subadult (~10 cm [4 inch] long) razor clams. Within this area, we only observed ~10 undisturbed “shows”. While flying the beaches in this sub-region, we observed several other isolated forage areas. We were unable to locate any “shows” on the beach surrounding this forage area or in other unforaged areas where we landed to check for razor clams. These observations suggest that foraging bears know or are able to locate isolated aggregations of razor clams within large expanses of beach and have developed a very effective search image that allows them to exploit a large proportion of the available prey within these small isolated areas. We observed similar patterns in the mid-intertidal mud flats where we observed brown bears foraging on softshell clams and evidence that brown bears and/or sea otters had recently been foraging.

The impact of predators on more abundant bivalves such as mussels and Baltic macomas is not clear. The importance of these bivalves to several shorebird species has been well documented (Robert Gill, pers. comm.; Sanger et al. 1984). Shorebirds in LACL forage intensely on Baltic macomas during migration and winter. Sea otters forage heavily on mussels in many areas during high tide (Van Blaricom et al. 2002; pers. observ.) Several sea duck species regularly forage on mussels and Baltic macomas in all three parks. Nevertheless, although fluctuating widely during a year (e.g., Lees et al. 1980), their abundance generally remains high (thousands per m²) throughout the year (e.g., Robert Gill, per. comm.; Lees et al. 1980, in prep.)

Based on this reconnaissance survey, it is unclear whether predator pressure plays a role in the variability in abundance or species composition observed within and among the parks. Brown bears, common on beaches in both LACL and KATM, were commonly observed foraging for razor clams on sand beaches in KATM where razor clam densities were generally low. In contrast, razor clam density was moderately high on sand beaches inside Chinitna Bay (0.35/m² at M2 in Clam Cove and 2.5/m² at SG2 west of Spring Point) and at S21 by Redoubt Point (0.39/m²) but we did not commonly observe evidence of bear foraging in LACL. However, they were foraging for softshell clams on mud flats. Apparently, foraging for razor clams by bears is probably discouraged by commercial interests at Polly Creek and possibly by families living in Chinitna Bay as well (Alan Bennett, pers. comm.) Consequently, it is possible that foraging activities are responsible for the differences in the abundance of razor clams between LACL and KATM. However, other factors may be responsible for this difference.

Otherwise, in view of differences in predator abundance patterns, the case does not appear strong that predators are affecting interpark differences. Predation pressure appears less important than differences in sediments, physical disturbance patterns, and oceanographic regimes.

Habitat Assessment

Habitat and biological diversity of the unconsolidated beaches varied markedly within and among the parks. Unpublished reports by Schoch (1994) and Mann (1996) provide definitive descriptions and detailed geomorphologic classifications of the KEFJ, LACL, and KATM shorelines. However, for this report, we have summarized our field observations and some general characterizations to support the interpretation of our results and recommendations for future monitoring. In KATM, both types of diversity were lower in the northern and central regions than in the southern region (Tables 3 and 4 and Appendix A). These patterns appear to be a reflection of the lack of embayments that provide opportunity for variations in exposure and variations in substrate type. The shoreline in the central and northern regions comprises primarily long uninterrupted stretches of sand beach. These beaches are mostly exposed directly to wave action out of southern Kamishak Bay, Cook Inlet, or Shelikof Strait, all of which produce extreme wave conditions. During our overflights, although we looked carefully, we did not see appreciable shell debris on these beaches. In the north, we saw evidence of foraging by brown bears on mud flats in the lee of the islets north of Douglas River but not on the exposed beaches. Consequently, we bypassed several planned sampling locations on the assumption that if we did not observe visible shell debris or foraging bears, it was likely these beaches had an impoverished bivalve fauna. This assumption may be incorrect in areas where humans may actively discourage bears from foraging on their “private” clam resources (e.g., Kaguyak). At most of the northern sites where we did perform ground surveys, we did not collect excavation or infaunal samples because the sites were obviously empty or impoverished based on haphazard digging with a shovel and extensive visual searches for clam “shows”.

The pattern observed in LACL is somewhat similar to that described for the northern region in KATM. The shoreline has only two large embayments with the remainder comprising long stretches of exposed beaches. In Chinitna Bay, at the southern boundary of LACL, mud flats characterize the shoreline of the inner bay while semiprotected sand beaches characterize the outer shore. These substrates support the expected bivalve assemblages typically observed on mud or sand beaches. The shoreline between Tuxedni Bay and Redoubt Point, near the northern boundary for LACL, comprises broad sandy beaches. In Tuxedni Bay, toward the northern boundary of LACL, the shorelines are typically mud flats with varying degrees of compaction and exposure to fresh water. The development of the bivalve fauna, typical of muddy habitats, varies directly with the salinity of the water column, i.e., the saltier the water, the better developed the bivalve assemblage. One of the richest habitats (previously surveyed but not visited in this study) is the northern point at the mouth of the bay frequented by high numbers of migratory shorebirds. Beaches of boulder/cobble, cobble, or broad sandy flats dominate the exposed shoreline between Chinitna and Tuxedni Bays. The shoreline between Tuxedni Bay and Redoubt Point, near the northern boundary for LACL, comprises broad sandy beaches. Many of these sandy beaches support populations of Pacific razor clams of varying density. On the beach north of Tuxedni Bay (Polly Creek), the razor clam population is

sufficiently dense that it supports a commercial fishery. Considerably more information is available for the beaches in LACL due to studies conducted by Lees and others starting in 1976 (Lees and Houghton 1977; Lees et al. 1980, in prep.); these should be consulted during the site selection process for LACL.

In Kenai Fjords National Park, the shoreline is dissected by a series of fjords that thrust many miles inland from the shores of the Gulf of Alaska. Geologically, this area is quite dynamic because of glacial retreat, seismic activity, and the precipitous nature of the upland landmasses. Generally, the shoreline is dominated by rocky habitat and the areas with unconsolidated substrates generally comprise coarse or mixed-soft sediments. As a rule, the beaches are narrow, relatively steep, and the sediments are coarse, often either gravel, cobble/boulder, or mixed-soft sediments. On the gravelly beaches, foolish mussels form extensive beds, especially in areas at higher elevations that are exposed to tidal currents but high enough to create a refuge from sea stars and other invertebrate predators. Populations of littleneck and butter clams are commonly found on semi-protected cobble/boulder beaches containing significant quantities of sand and silt (i.e., mixed-soft sediments). Several mud flats occur in protected bays or lagoons; these usually support moderate populations of softshell clams and Baltic macomas.

Clam populations that are likely candidates for sampling in the long-term monitoring program occur at both lower and middle tidal elevations in all parks. The populations at lower elevations are typically found on sandy or mixed-soft sediments. Populations at higher elevations typically occur in muddy substrates that protect them from desiccation during low tide. Employing a mixture of these types of sites provides an opportunity for sampling diverse types of organisms and habitats, and taking advantage of both the low and high low tide during a spring-tide series. Sampling only in mud flats in the middle tide range would open up greater sampling opportunities because sites can be sampled during both spring- and neap-tide series. However, sampling would be limited to softshell clams and Baltic macomas.

The reconnaissance surveys indicate that the number of appropriate beaches in the parks is limited as few exhibit sufficiently sizable mature populations of long-lived species to support a long-term monitoring program. Because bivalve assemblages are impoverished on many beaches, selection of sampling locations and sentinel species in all three areas will require great care. It may be that, depending on species, a fixed-site sampling scheme may not be practical; a stratified-random scheme may have to be implemented instead to reduce sampling pressure on local populations.

The following suitability criteria are recommended for selecting sampling habitats:

- 1) Ease of access by the logistical support most applicable in the specific park.
- 2) Temporal availability; tidal elevation is important.

- 3) Substrate type is appropriate for specific sentinel species.
- 4) Sediment type facilitates ease of sampling and/or processing the samples.
- 5) If possible, locate sampling sites in a manner that facilitates sample processing, i.e., near water.

Regarding access, options include helicopters in KATM, KEFJ, and LACL, and vessels in KEFJ and some areas in KATM. The advantages of helicopters are the ability to: 1) cover large areas during a low tide and 2) land at sites where the breadth of the beach or surf precludes sampling a selected assemblage. Major disadvantages include the weight limitation, which limits the size of the sampling crew and precludes taking large volumes of sediment back to the staging area for processing more efficiently after a tide window closes, and the cost. The advantages of sampling with skiffs from a support vessel are that it allows operating with a larger sampling crew and heavy unprocessed samples can be taken back to the support vessel or staging area for more efficiently and timely processing. The disadvantages are the limited range that can be traveled during a tide window, limitations in landing sites because of swell conditions, and the distance a crew may need to walk across muddy or sandy flats to reach the desired sampling populations at higher tidal elevations.

Regarding temporal constraints, sample collection in some substrates may require at least one hour if the samples must be processed on site. It is preferable that the sites sampled at either the middle or lower level be located within a similar elevation range (e.g., 1 foot above MLLW $\pm$ 1 foot). During a typical low tide window, this will allow a crew to sample at least three or four sites per tide window. Sites available only during extreme low tides probably should not be considered due to their highly limited access.

Regarding sediment type, muddy sediments require much longer to process than sandy sediments but often, bivalve density is higher in mud substrates so the samples produced are of better quality and fewer replicates are required to attain statistical significance. Optimizing the sample washing equipment could partially resolve this issue, especially if the samples can be transported back to a staging area for processing in the period between low-tide windows.

Recommended Bivalve Assemblage

In view of the abundance and size of the bivalves found in this study, collecting or enumerating macrofaunal bivalves by excavation sampling or band transects is more appropriate for satisfying the objectives of long-term monitoring than collecting monitoring with data from microinfaunal cores. Moreover the macrofaunal bivalves are species more often exploited by the charismatic predators and, because they are long-lived, they are far more representative of long-term conditions than their smaller counterparts.

Generally, a monitoring program will be better served if the species chosen for monitoring are relatively large, long-lived, and common. This makes species

identification and enumeration easier and has benefits in processing samples in preparation for chemical analysis and in analyzing tissue concentrations of contaminants (chemistry tissue samples generally need ~10 g wet weight for good analytical sensitivity). Sampling for a long-term monitoring program should be conducted in areas supporting stable mature populations of long-lived species. The program should include nearby or replicate sites for each species because of the possibility that one or more populations may disappear during the program, as has been observed at sites in the PWS LTEMP mussel sampling program (W. Driskell, pers. observ.)

Working with macrobivalve species provides greater insights into long-term conditions at a site. These animals are the long-lived “tree” (rather than “weed”) species inhabiting the sediments and provide insight into long-term conditions at a site. If the population has sufficient abundance, it can support a tissue-sampling program for contaminants for a substantial period. In contrast, it is difficult to obtain adequate biomass to support a tissue-sampling program with microinfaunal bivalves. These organisms provide insight into recruitment patterns and the smaller, “weed” species more reflective of short-term events but do not provide insight into long-term patterns. Moreover, sample processing is a costly, time-consuming laboratory activity. An exception would, of course, be when the study question involved a specific prey as the species of interest (e.g., diving or dabbling ducks feeding on small bivalves such as Baltic macomas). In this case, sampling methods could be adjusted to optimize efforts.

Functional Attributes of Sampled Bivalves

Two important functional attributes in our consideration of sentinel species are whether they live in or on the sediment and how they feed. The bivalves observed during this study typically dwell in one of three different ways. Some, such as foolish mussels, have a mostly surficial lifestyle, i.e., they live on top of the sediments. Some species are nestlers, i.e., they nestle at the surface among the larger particles or in burrows created by burrowing organisms. These include the Arctic hiatella, northern horsemussel, and robust mysella. But the most common forms are burrowing clams, i.e., those that live burrowed in the sediments. All of the burrowers observed during this study connect to the overlying surface water through incurrent and excurrent siphons of varying length. These species extend the siphons through a semi-permanent or temporary burrows to connect to the surface of the sediment and into the water column and obtain food and oxygenated water or to discharge wastes.

The species collected have predominantly two feeding modes. All but the macomas and tellinids are suspension feeders. They pump large volumes of water over the gills and filter from that water the suspended plankton and/or particulate detrital matter that is then passed into the digestive tract for nutrition. In contrast, the macomas and tellinids are facultative suspension/deposit feeders. Depending on the velocity of the currents sweeping their habitat, they can either function as a suspension feeder or, under calmer conditions, they use their long, flexible incurrent siphons like a vacuum-cleaner hose to suck up a

concentrated layer of organic matter from the surface of the sediments around their siphon holes.

These different feeding modes have implications for contaminant assimilation. All of these species derive their nutrition within a few centimeters of, or at, the surface of the sediment. They depend to varying degrees on plankton or larger organic particles, in which contaminants are partitioned in different ways. Thus, some species may be better contaminant indicators than others. Suitability in feeding modes for examination of tissue contaminants is generally ranked, from most to least favorable as follows: suspension feeder >> surface deposit feeder >> subsurface deposit feeder (not found in this survey). The only species currently being sampled routinely for contaminants in Alaska is the foolish mussel, a suspension feeder.

In addition to the organic matter ingested for nutrition, bivalves generally ingest large quantities of inorganic particles along with associated contaminants. Unless these ingested contaminants are eliminated before analytical processing, they would be erroneously interpreted as part of the contaminant body burden. Consequently, all specimens collected for measurement of tissue contaminants should be depurated in fresh seawater to allow them to purge their stomach contents since the included contaminants would skew the analytical results. An alternative is to selectively sample individual tissues, i.e., non-gut tract.

Another approach to contaminant monitoring is to directly measure metabolic impact rather than contaminant load. Biomarker laboratories routinely use gene and protein expression analyses and enzyme reactions to detect changes in various metabolic and detoxification enzymes in vertebrate and invertebrate species. For example, endpoints may include detecting changes in cytochrome P450 and a variety of antioxidant enzymes/factors such as glutathione. Many other biomarkers may be used, particularly those indicative of reproductive changes (vitellogenin protein, thyroid hormones), oxidative stress (DNA strand breaks), genotoxicity (DNA damage), and general stress (heat-shock proteins). We are currently impressed with the potential of the very inexpensive Comet Assay as a genotoxicity test for petroleum PAH compounds (Lee and Steinert 2003) and are exploring its use with the LTEMP monitoring program which includes one site in Aialik Bay.

Potential Sentinel Species

During the surveys, we observed ten species that we consider potential sentinel species for the long-term monitoring program, based on their distribution patterns (Table 11). The only two species occurring in all regions (Baltic macoma and softshell clam) occur mainly in mud flats. All remaining species, except for Alaska razor clams, occurred in two parks. While Pacific razor clams are abundant in LACL, our survey suggests it is rare in intertidal habitats in KATM. Thus, the species available for monitoring differ substantially among regions, precluding selection of species that can be monitored in all parks in habitats other than mud.

INTERTIDAL BIVALVES IN SOUTHWEST ALASKA NETWORK PARKS

Foolish mussels are the easiest bivalve to sample in KEFJ, where they form extensive beds on gravel and cobble shores in many areas throughout the park. In contrast, they were not common in KATM and were not observed in LACL (Table 11). However, because they also occur on rock and we have observed sizeable populations of mature mussels on Gull Island, in Chinitna Bay in LACL, it would be possible to obtain adequate samples for comparative contaminant sampling in all three parks if desired. Due to their scarcity in two of the parks, however, it may be a challenge to satisfy spatial requirements of a sampling plan for those parks.

Table 11. Summary of number and percent of sites at which major bivalves were observed in excavation samples or visually at sites surveyed in KATM, KEFJ, and LACL in June 2004-2005.

Sediment Type	Grav-el	Mud			Sand			Mixed-soft		
Species	Foolish Mussel	Baltic Macoma	Softshell Clam	False Softshell Clam	Arctic Surf Clam	Alaska Razor Clam	Pacific Razor Clam	Oval Macoma	Butter Clam	Littleneck Clam
Park										
KATM – No. of Sites	7	14	10	4	8	6	1	8	6	1
% of Sites	26	52	37	15	30	14	4	30	22	4
KEFJ– No. of Sites	24	21	2	4	0	0	0	11	10	13
% of Sites	71	62	6	12	0	0	0	32	30	38
LACL– No. of Sites	0	5	4	0	1	0	4	0	0	0
% of Sites	0	56	44	0	11	0	44	0	0	0
Feeding Mode	SF*	FSDf	SF	SF	SF	SF	SF	FSDf	SF	SF

* SF – Suspension feeder; FSDf – Facultative suspension/deposit feeder

The three species on mud flats provide good alternatives for sampling in that habitat (Table 11). All appear to be exploited by various predators. We saw evidence of diving duck and shorebirds feeding on Baltic macoma and sea otters and brown bears feeding on softshell clams. Since these two species are common in all three parks, they are probably the best candidates for monitoring mud flats.

Neither razor clam species would be appropriate in more than one park (Table 11). Both are exploited in their respective parks, the Pacific razor clam in LACL by commercial and sport fishermen and possibly brown bears, and the Alaska razor clam in KATM by brown bears and possibly sea otters and sport fishermen. Their absence in KEFJ is not important in terms of sampling design or biological significance simply because comparable sand beaches are apparently absent there. In KATM, it is possible that further exploration might locate populations of Pacific razor clams so that the same species could be compared between KATM and LACL. However, it may be a moot point since it is likely the metabolism of the two species is sufficiently similar that they would deal with contaminants in a comparable manner. Thus, it would probably be acceptable to monitor the sand habitats in LACL and KATM using different razor clam species. Arctic surfclams were observed in two parks, but despite considerable effort we were only successful in collecting subadults. Consequently, that species is probably not a good candidate unless a better method can be used to collect specimens.

Of the three species observed in mixed-soft substrates (Table 11), butter and littleneck clams seem to be the best alternatives because they are larger and create distinctive burrows that are often conspicuous when they squirt. Both species are used for food by sea otters. Oval macomas are smaller and less conspicuous and we are not aware that vertebrate predators use this macoma for food. None of these species can be used in LACL because they have not been observed that far north in Cook Inlet during any of our previous surveys.

We suggest the following suitability criteria be used when selecting sentinel species:

- 1) A feeding mode that provides considerable exposure to water-borne (dissolved or particulate) or floating contaminants.
- 2) Ease of detection and collection in the field.
- 3) Adequate population size and density to support efficient collection and long-term sampling. Density at a site should be high enough that ten samples will provide adequate replication for statistical power to detect a 50-percent change with the method of choice.
- 4) Individual clams large enough to minimize collection effort in the field and processing effort in the analytical laboratory.
- 5) Geographic distributions allowing monitoring in as many parks as possible.
- 6) A mix of species providing good coverage of the important habitat types.
- 7) Utilized as food by the major vertebrate predators in the parks.
- 8) Sensitivity to environmental change.

INTERTIDAL BIVALVES IN SOUTHWEST ALASKA NETWORK PARKS

While the last criterion is desirable, it probably cannot be evaluated in this context. While each of these species has relatively distinctive environmental requirements, within their various specific habitats, they appear to exhibit wide ranges of tolerance to differences or changes in water quality variables (e.g., temperature, salinity, turbidity, etc.), and sediment characteristics. Consequently, these species will probably not exhibit responses unless a variable (e.g., temperature or salinity) changes quite markedly. Moreover, their populations probably exhibit natural fluctuations or cyclical changes that could be misinterpreted as responses to autocorrelated environmental change but for which we have no acceptable explanations. We suggest the long-term monitoring program should be very careful about attributing observed changes in populations to observed environmental changes without experimental manipulations or very strong empirical evidence to support and confirm the hypotheses.

We have provided an example of a suitability analysis for the species identified as the most suitable for selection as sentinel species (Table 12). The species have been segregated by sediment habitat. Based on this analysis, it appears that, in the SWAN parks, mussels are the most suitable in gravel/mixed-soft habitats, littleneck and butter clams are most suitable in mixed-soft habitats, and softshell clams are most appropriate in muddy habitats. None of the clams on sandy habitats appear to offer a good alternative, because either they are not found in more than one park or they are sparse. It is likely that razor clams would be most suitable in this habitat because one or the other species can be readily collected in KATM or LACL.

Table 12. Suitability scores* for potential sentinel bivalves in KATM, KEFJ, and LACL in June 2004-2005.

Suitability Criterion/ Species	Appropriate Feeding Mode	Ease of Detection and Collection	Adequate Populations	Large Individual Clams	Appropriate Geographic Distribution	Major Vertebrate Predator Food	Sensitivity to Environmental Change	Total Score	Habitat
Foolish Mussel	1	1	1	1	1	1	3	9	G/MS
Butter Clam	1	1	2	1	2	2	3	12	MS
Littleneck Clam	1	1	2	1	2	2	3	12	MS
Oval Macoma	2	3	2	2	2	3	3	17	MS

INTERTIDAL BIVALVES IN SOUTHWEST ALASKA NETWORK PARKS

Suitability Criterion/ Species	Appropriate Feeding Mode	Ease of Detection and Collection	Adequate Populations	Large Individual Clams	Appropriate Geographic Distribution	Major Vertebrate Predator Food	Sensitivity to Environmental Change	Total Score	Habitat
Arctic Surf Clam	1	1	2	1	2	2	3	12	S
Alaska Razor Clam	1	2	2	1	3	2	3	14	S
Pacific Razor Clam	1	2	2	1	3	2	3	14	S
Baltic Macoma	2	2	1	2	1	2	3	13	M
Softshell Clam	1	1	1	1	1	1	3	9	M
False Softshell Clam	1	1	1	1	2	1	3	10	M

* 1 = Yes, 2 = Partial, 3 = No

During the conduct of these surveys in the three SWAN parks, we have gained considerable insights into the intricacies of sampling in these diverse but often relatively depauperate habitats. Based on these experiences, we prepared discussions regarding desirable features for a long-term monitoring program in these parks, some aspects of sampling design, suggestions for population and tissue sampling, sampling frequency, and environmental monitoring. These discussions are included in Appendix H.

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during the surveys in KEFJ and LACL kept the field efforts lighter and more enjoyable.

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APPENDIX A

Appendix A-1 Sites visited in during the May-June 2004 intertidal reconnaissance survey in North and West Arms, Nuka Bay, KEFJ

Site No./ Date/ Time	Description of Site Location	Substratum; Dominant Bivalves Observed	Approx. Tidal Elev. (ft)	GPS Coordinates
W50; 6/2/04, 0610	Northern end of North Arm	Silty gravel/cobble/sand; <i>Macoma balthica</i> , <i>Mytilus</i>	-0.6	N59.606317° W150.52020°
W49; 6/2/04, 0538	NW embayment, head of North Arm	Flat gravel/mud; shale pebble/ cobble w/light shell debris; None	-0.6	N59.59505° W150.55745°
W51; 6/2/04, 0753	NE embayment, head of North Arm	Sand/mud tidal flat; <i>Macoma balthica</i> , <i>Macoma</i> , <i>Mya</i> <i>truncata</i> , <i>Saxidomus</i>	-1.4	N59.59797° W150.50345°
G6**; 6/2/04, 0545	Rocky shore at head of North Arm	Boulder/cobble pocket beach, only small pockets of silty sand; <i>Protothaca</i>	0.0	59.58622°N 150.55838°W
W46; 6/2/04, 0805	Pilot Harbor, North Arm	Soft gravelly mud w/eelgrass; <i>Mya</i> , <i>Macoma balthica</i>	-2.8	59.58248°N 150.49313°W
S31; 6/2/04, 0920	N. end, Cabin Bay, North Arm	Clean sand, sandy gravel, coarse sand, no shell debris; <i>Saxidomus</i> , <i>Protothaca</i> , <i>Mya</i> <i>truncata</i> , <i>Macoma</i> <i>balthica</i>	-0.5	59.56633°N 150.51120°W
W47; 6/2/04, 0950	NPS Park cabin, North Arm	Shale gravel, gently sloping; <i>Saxidomus</i> ?	+1.0	59.55228°N 150.52480°W
W48**; 5/31/04, 1900	Beauty Bay, North Arm	Gravel, sand, fines. Broad flat river delta; None	+4.2	59.54585°N 150.65043°W
W38; 6/1/04, 0854	Head, Palisade Lagoon, Surprise Bay, West Arm	Very flat sand/gravel delta; <i>Macoma</i> <i>balthica</i> , <i>Mya</i> , <i>Mytilus</i>	+1.4	59.52757N 150.47725°W

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Site No./ Date/ Time	Description of Site Location	Substratum; Dominant Bivalves Observed	Approx. Tidal Elev. (ft)	GPS Coordinates
W48A; 6/2/04, 1835	Shelter Cove, Beauty Bay, West Arm	Mud/gravel flats; well- developed mussel bed; <i>Mytilus</i> , <i>Macoma balthica</i>	+2.4	59.52422°N 150.63637°W
SG111A; 6/1/04, 0736	Palisade Lagoon Spit, Surprise Bay, West Arm	Angular boulder/cobble armor, gravel, mud, shell debris; <i>Hiatella</i> , <i>Protothaca</i> , <i>Macoma</i>	-1.0	59.51988°N 150.48025°W
SG153; 6/1/04, 0805	Old Gold Mine site, Surprise Bay, West Arm	Fine/moderate shingle, sand, cobble; <i>Protothaca</i> , <i>Saxidomus</i> , <i>Mytilus</i>	-0.3	59.51257°N 150.49020°W
SG146; 6/1/04, 0630	Ariadne Island. Surprise Bay, West Arm	Medium coarse sand, shell, gravel; <i>Saxidomus</i> , <i>Protothaca</i>	-0.2	59.48137°N 150.51395°W
W53; 6/1/04, 0540	Ariadne Cove. Surprise Bay, West Arm	Cobble armor, gravel, sand, mud. Stream delta; <i>Mya truncata</i> ?	-0.8	59.47498°N 150.50355°W
SG145*; 6/1/04, 0530	Ariadne Cove. Surprise Bay, West Arm	Cobble/shingle, boulders w/some sand; <i>Hiatella</i> , <i>Protothaca</i> and <i>Saxidomus</i>	-0.4	59.47480°N 150.51108°W

* Some samples collected

** Samples not collected

APPENDIX A

Appendix A-2. Sites visited in during the May-June 2004 intertidal reconnaissance survey in McCarty Fjord, KEFJ.

Site No./ Date/ Time	Description of Site Location	Substratum; Dominant Bivalves Observed	Approx. Tidal Elev. (ft)	GPS Coordinates
SG130B**; 6/4/04, 1123	North end, McCarty Fjord	Gravel/cobble; <i>Mytilus</i>	+0.9	59.72057°N 150.21750°W
SG130A**; 6/4/04, 1115	North end, McCarty Fjord	Armored boulder/cobble, gravel, steep gradient; <i>Mytilus</i>	-0.2	59.71762°N 150.21903°W
SG122; 6/4/02, 0850	West central McCarty Fjord	1. Glacial flour over gravel; <i>M. balthica</i> , <i>Macoma</i> . 2. Boulder/ cobble, glacial flour veneer; <i>Mytilus</i>	-3.8	1. 59.64113°N 150.30812°W 2. 59.64112°N 150.30885°W
W42; 6/4/04, 0912	West central McCarty Fjord	Soft mud below cobble/boulder beach; <i>Mya</i> , <i>Macoma</i>	-4.0	59.63573°N 150.31522°W
W43**; 6/4/04, 0730	Cove, east central McCarty Fjord	Cobble; <i>Mytilus</i>	-1.7	59.63092°N 150.26463°W
SG121; 6/4/04, 0724	West central McCarty Fjord	Cobble, gravel, mud, sand; <i>Mytilus</i> , <i>Hiatella</i> , <i>Macoma</i> <i>balthica</i>	-1.5	59.63040°N 150.31903°W
W39; 6/2/04, 1850	North head of James Lagoon, McCarty Fjord	Compact clean sand, hard w/gravel; <i>Mya</i> , <i>Macoma balthica</i>	+2.1	59.58218°N 150.41077°W
SG115A; 6/2/04, 1904	James Lagoon mussel bar, McCarty Fjord	Gravel/mud bar; <i>Mytilus</i>	+2.0	59.56613°N 150.40817°W
S24; 6/3/04, 0715	Moraine beach, McCarty Fjord	Exposed gravel and sand; cobble platform @ 0'; sand below	-2.24	59.54494°N 150.33792°W

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Site No./ Date/ Time	Description of Site Location	Substratum; Dominant Bivalves Observed	Approx. Tidal Elev. (ft)	GPS Coordinates
S24SG; 6/3/04, 0829	Moraine spit, McCarty Fjord	Armored boulder/cobble / sand/gravel; <i>Mytilus</i>	-3.9	59.54065°N 150.34500W°
W37**; 6/4/04	Pond north of entrance to McCarty Lagoon	Sand; gravel/cobble; freshwater pond; None	Appears above tidal influen ce	59.53697°N 150.34442°W
SG103*; 6/3/04, 1010	Mouth of McCarty Lagoon	Armored cobble/gravel/ sand delta; None	-0.7	59.53513°W 150.34838°W
W36A; 6/3/04, 0650	North side, McCarty Lagoon	Gravel/cobble along channel w/shell debris; <i>Mytilus</i> , <i>Macoma balthica</i>	-1.7	59.53198°N 150.32650°W
W36B; 6/3/04, 0923	North side, McCarty Lagoon	Silty gravel w/cobble, shell debris, <i>Protothaca</i> , <i>Saxidomus</i>	-2.3	59.53198°N 150.32650°W

* Some samples collected

** Samples not collected

APPENDIX A

Appendix A-3. Sites visited in during the May-June 2004 intertidal reconnaissance survey in Northwestern Fjord, KEFJ.

Site No./ Date/ Time	Description of Site Location	Substratum; Dominant Bivalves Observed	Approx. Tidal Elev. (ft)	GPS Coordinates
M2A, 6/5/04, 0800	North side, outer Northwestern Fjord	Sand flat below gravel and sand; <i>M. balthica</i>	-1.1	59.77012°N 149.93012°W
SG43, 6/5/04, 0856	North side, outer Northwestern Fjord	Sand flat, broad; <i>M. balthica</i>	-3.1	59.76763°N 149.91723°W
W15A**; 6/5/04, 0815	North side, outer Northwestern Fjord	Cobble, gravel, sand, stream delta; <i>Mytilus</i>	-1.5	59.77035°N 149.93317°W
S11, 6/5/04, 0856	North side, outer Northwestern Fjord	Cobble, sand, gravel; <i>M. balthica</i> , <i>Clinocardium</i>	-3.7	59.76967°N 149.90873°W
M2; 6/5/04, 0905	North side, outer Northwestern Fjord	Cobble/sand/ gravel w/scattered boulders; <i>Protothaca</i> , <i>Saxidomus</i>	-2.6	59.76888°N 149.91378°W
W15*; 6/5/04, 0840	North side, outer Northwestern Fjord	Gravelly unconsolidated unstable sand, river delta; None	-2.3	59.76818°N 149.92868°W
W24 **; 6/5/04, 1300	Big Slough, at SE corner of Northwestern Lagoon	Bedrock at entrance, sand/mud flats inside w/ eelgrass; <i>Mya</i> , <i>Macoma balthica</i> , <i>Mytilus</i>	+3.5	59.72462°N 149.93225°W
M5, 6/5/04, 1107	South side of NW Lagoon (Otter Cove)	Armored cobble below fine sand below cobble; <i>Mytilus</i> , <i>Protothaca</i>	-2.1	59.72255°N 149.94702°W
W26; 6/5/04, 1124	West side of NW Lagoon (Otter Cove)	Mud with jagged cobbles, boulders; <i>Mya</i> , <i>Macoma</i>	-0.4	59.71885°N 149.96677°W

* Some samples collected

** Samples not collected

APPENDIX A

Appendix A-4. Sites visited in Aialik Bay during the May-June 2004 intertidal reconnaissance survey in KEFJ.

Site No./ Date/ Time	Description of Site Location	Substratum; Dominant Bivalves Observed	Approx. Tidal Elev. (ft)	GPS Coordinates
W10*; 6/6/041058	Head of Aialik Bay, east side	Sandy gravel/cobble/ boulder; <i>Mytilus</i>	-2.0	59.95042°N 149.68607°W
M1; 6/6/04, 0955	Head of Aialik Bay, west side	Clean sand, cobble/gravel, no shell debris; None	-1.9	59.95432°N 149.71637°W
Reef**; 6/6/04, 1200	Frozen Rock, head of Aialik Bay,	Smooth bedrock; <i>Mytilus</i>	-1.4	59.94120°N 149.70577°W
SG27**; 6/6/04, 0845	Head of Aialik Bay, east side	Imbricated cobble/boulder, little sand or silt; <i>Mytilus</i>	-0.3	59.93395°N 149.66925°W
SG32A*; 6/6/04, 1245	Head of Aialik Bay, west side	Fine sand/gravel bar in middle of back beach; None	+0.7	59.93335°N 149.73380°W
SG32**; 6/6/04, 1235	Head of Aialik Bay, west side	Shingle/cobble/ boulder back beach; <i>Mytilus</i>	0.0	59.93210°N 149.73447°W
Landing site**; 6/6/04, 1215	Head of Aialik Bay, west side	Boulder/cobble/ gravel w/glacial flour veneer; <i>Mytilus</i>	-0.8	59.92880°N 149.73115°W
W4**; 6/7/04, 0945	Cove north of Abra Cove, central Aialik Bay	Cobble/gravel/ sand/mud, highly consolidated; <i>Mytilus</i>	+0.15	59.91210°N 149.65630°W
S31; 6/6/04, 1106	Slate Island, north Aialik Bay	Armored slate cobble w/sand, gravel; <i>Mytilus</i>	-1.85	59.90900°N 149.71790°W
S30*; 6/6/04, 1002	Slate Is. Passage, north Aialik Bay	Armored boulder/cobble w/gravel, sand, mud; <i>Mytilus</i> , <i>Protothaca</i> , <i>M. balthica</i>	-2.9	59.90498°N 149.72270°W
G1; 6/6/04, 1227	Abra Cove, central Aialik Bay	Black gravel/sand below cobble; <i>Mytilus</i>	-0.3	59.89950°N 149.64232°W
G1**;	Central Aialik	Cobble; <i>Mytilus</i>	+0.2	59.89887°N

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Site No./ Date/ Time	Description of Site Location	Substratum; Dominant Bivalves Observed	Approx. Tidal Elev. (ft)	GPS Coordinates
6/6/04, 1240	Bay			149.63893°W
G1A**; 6/6/04, 1250	Central Aialik Bay	Sand/gravel w/scattered boulders; <i>Mytilus</i>	+0.7	59.89857°N 149.63838°W
G1A; 6/7/04, 1039	Abra Cove, central Aialik Bay	Sand/gravel w/scattered boulders; <i>Saxidomus</i> , <i>Mytilus</i> , <i>Protothaca</i> , <i>Clinocardium</i>	-1.6	59.89850°N 150.63905°W
W9; 6/6/04, 0843	Slate Is. Passage spit, north Aialik Bay	Armored cobble w/sand and gravel; <i>Mytilus</i> , <i>M. balthica</i>	-0.2	59.88723°N 149.71880°W
SG11; 6/7/04, 1230	South cove, Coleman Bay, central Aialik Bay	Cobble/gravel spit, steeply sloped; None	-1.2	59.85982°N 149.64265°W
Ranger**; 6/7/04, 1250	Ranger Station Cove, Aialik Bay	Clean rounded gravel/ cobble, little sand, silt, or shell debris; None	-0.7	59.84988°N 149.65987°W
SG3*; 6/7/04, 1135	North Tooth Cove, Aialik Bay	Shingle/shale/ gravel w/sand/ shell hash/ silt; <i>Protothaca</i> , <i>Diplodonta</i>	-2.0	59.82668°N 149.66317°W
W1A & W1B**; 6/7/04, 0930-1100	Head of South Tooth Cove, Aialik Bay	Rounded clean gravel/cobble to Boulder/cobble fan; <i>Mytilus</i> , <i>Hiatella</i> , <i>Saxidomus</i>	+0.8 to - 1.9	59.80668°N 149.64358°W

* Some samples collected

** Samples not collected

APPENDIX B

Sites visited during the June-July 2004 intertidal reconnaissance survey in Lake Clark National Park & Preserve.

Site No./ Date/ Time	Description of Site Location	Substratum; Dominant Bivalves Observed	Approx. Tidal Elev. (ft)	GPS Coordinates
Cook Inlet North of Tuxedni Bay (1 site)				
S21; 7/2/04, 1020	S. of Redoubt Point, 1 km	Firm fine rippled sand, slight silt; <i>Siliqua</i>	-4.5	60.27795°N 152.42347°W
Tuxedni Bay (8 site)				
W10; 7/1/04, 1945	S. side, upper Tuxedni Bay, across from Magnetic Is.	Sloppy mud; prob. none	>+5	60.24000°N 152.87888°W
S17; 7/1/04, 2029	W. side of Squarehead Cove	Sloppy mud; prob. none	>+5	60.22417°N 152.71167°W
W22; 7/1/04, 2040	SW corner of Squarehead Cove	Mixture of sloppy mud, rel. firm & muddy grave/cobble; <i>M. balthica</i> , <i>Mya</i>	>+5	60.22402°N 152.63272°W
S12; 7/1/04, 1955	South side, inner Tuxedni Bay	Firm to sloppy mud w/large cracks in upper area; None	>+10	60.19352°N 152.76275°W
S10; 6/30/04, 2100	Bight north of Fossil Point	Soft mud veneer over sand, some shell debris; <i>M. balthica</i>	Est. elev. +5	60.16643°N 152.70122°W
W8A; 6/30/04, 2000	Bight south of Fossil Point, Tuxedni Channel	Soft mud veneer over sand, some shell debris; <i>M. balthica</i>	Est. elev. +5	60.16292°N 152.67660°W
S8; 7/2/04, 0745	Middle, west side, Tuxedni Channel	Firm mud/sand over gravel; <i>Mya</i> , <i>M. balthica</i>	Est. elev. +4	60.11893°N 152.63068°W
S7; 7/2/04, 1136	South point of Tuxedni Channel	Silty gravel/cobble; None	~-1.3	60.98960°N 152.58688°W

APPENDIX B

Site No./ Date/ Time	Description of Site Location	Substratum; Dominant Bivalves Observed	Approx. Tidal Elev. (ft)	GPS Coordinates
Cook Inlet Between Tuxedni Bay and Chinitna Bay (5 sites)				
W6**; 6/30/04, 1930	Mouth of Johnson River, outer bar	Coarse sand, gravel; <i>Siliqua, Mactromeris</i>	Est. elev. +5	60.01142°N 152.60483°W
W6A; 6/30/04, 1945	Mouth of Johnson River, inner pocket	Soft glacial flour over compact mud; None	Est. elev. +5	60.01192°N 152.65445°W
W5; 7/1/04, 0950	Silver Salmon Creek Lodge lagoon	Muddy gravel fan inside storm berm; None	-4.8	59.98263°N 152.63553°W
M7; 7/1/04, 0910	Silver Salmon Lodge Beach	Clean rippled sand; <i>Siliqua</i>	-3.5	59.98272°N 152.63545°W
M6; 7/1/04, 1015	N. of Spring Point	Large cobble, small to medium boulders, no shell debris; <i>Mytilus</i>	Above -3.6	59.88750°N 152.79167°W
Chinitna Bay (7 sites)				
SG1; 7/2/04; 0736	N. shore of Chinitna Bay, 4.5 nm W of Clam Cove	Clean sand flat w/ripple marks; <i>Siliqua, Mactromeris</i>	-1.6	59.88303°N 153.03113°W
M2; 7/1/04, 0750	N. shore of Chinitna Bay, Clam Cove	Clean sand below gravel sand beach face; <i>Siliqua</i> , <i>Mactromeris</i>	-1.5	59.87887°N 152.94953°W
SG2; 7/1/04, 1025	Bight W. of Spring Point	Sand beach with cobble/boulder above and below; <i>Siliqua</i>	-2.0	59.87613°N 152.84425°W
W1; 7/1/04, 1145	SW of Glacier Spit, Chinitna Bay	Firm mud over sand/gravel, shallow meandering drainage channels; <i>M. balthica, Mya</i>	+5.5	59.85582°N 153.15267°W
W1A**;	SW of Glacier	Soft mud, major	>+6	59.85672°N

APPENDIX B

Site No./ Date/ Time	Description of Site Location	Substratum; Dominant Bivalves Observed	Approx. Tidal Elev. (ft)	GPS Coordinates
7/1/04, 1245	Spit, Chinitna Bay	drainage channel, wetlands; None		153.15367°W
S1**; 7/1/04, 0715	Flat between Chinitna River and Glacier Creek	Muddy marsh; None	Est. elev. >+8	59.84245°N 153.15103°W
S1A**; 7/1/04, 0740	Flat between Chinitna River and Glacier Creek	Soft muddy sand w/braided stream, no shell debris; None	Est. elev. >+1	59.84200°N 153.15032°W

* Some samples collected

** Samples not collected

APPENDIX C

Sites visited in during the June 2005 intertidal reconnaissance survey in Katmai NP (KATM). Sites are ordered from south to north.

Site No./ Date/ Time	Description of Site Location	Substratum; Dominant Bivalves Observed	Approx . Tidal Elev. (ft)	GPS Coordinates (NAD 27)
Southern region				
K12*; 6/22/05, 2049	Takli Is., Amalik Bay	Moderately sorted medium/fine sand; Baltic macoma, softshell clam	~+8.0	N58° 03.394' W154° 30.255'
K8*; 6/23/05, 1113	Mink Is., western island in Amalik Bay	Very well sorted medium sand and shell hash/mixed soft; butter and littleneck clam and Baltic macoma	-0.3	N58° 04.765' W154° 31.806'
K10*; 6/23/05, 1015	Amalik Bay, Geographic Harbor, SE side	Well sorted medium/fine sand; oval and Baltic macoma, salmon tellin, false softshell	~-3.0	N58° 06.915' W154° 36.447'
K18*; 6/23/05, 0920	Kinak Bay	Well sorted medium/fine sand; butter & gaper clams	-0.8	N58° 07.444' W154° 27.319'
K19*; 6/23/05, 0825	Missak Bay	Well sorted fine/medium sand; Alaska razor clam, oval macoma	-0.3	N58° 08.034' W154° 17.174'
K21*; 6/22/05, 1945	Kuliak Lagoon	Moderately sorted fine/medium sand; Baltic macoma, softshell clam	~+4.6	N58° 11.258' W154° 16.050'
K22*; 6/22/05, 0840	Kafli Bay, Kafli Lagoon	Well sorted fine/medium sand, considerable shell hash; oval and Baltic macoma, basket cockle	-2.5	N58° 15.816' W154° 12.630'

APPENDIX C

Site No./ Date/ Time	Description of Site Location	Substratum; Dominant Bivalves Observed	Approx . Tidal Elev. (ft)	GPS Coordinates (NAD 27)
KC*; 6/22/05, 0945	Kukak Bay, near Kukak Cannery	Well sorted fine/medium sand; oval macoma, basket cockle, butter clam	-3.1	N58° 19.198' W154° 11.075'
DC*; 6/24/05, 2210	Kukak Bay, Lodge Cove, Devil's Cove	Moderately sorted fine silty sand; Baltic macoma, softshell clam, basket cockle	~+7.0	N58° 21.023' W154° 07.448'
K28*; 6/22/05, 1045	Kukak Bay, Devil's Cove	Well sorted medium/coarse sand w/gravel; gaper and butter clams, false softshell	+0.2	N58° 21.324' W154° 10.620'
Central Region				
K30*; 6/23/05, 2228, 6/25/05, 0955	Shoals W of Ninaglak Is. in Hallo Bay	Well sorted medium sand, considerable shells and shell hash; Arctic surf clam	~+4.8; shoals flood at +7.1	N58° 27.637' W154° 00.337', N58° 27.692' W154° 00.245'
K31*; 6/25/05, 1025	North end, Hallo Bay	Moderately sorted fine sand; softshell clam, Baltic macoma	-1.3	N58° 29.120' W154° 02.527'
K32A**; 6/23/05, 2055	Outer Chiniak Lagoon, no. of Cape Chiniak Lagoon	Hard-packed muddy fine sand; softshell clam, Baltic macoma	~+10	N58° 31.234' W153° 55.590'
K32B**; 6/23/05, 2125	Outer Chiniak Lagoon, no. of Cape Chiniak Lagoon	Hard-packed muddy fine sand; softshell clam, Baltic macoma	~+10	N58° 31.260' W153° 55.608'
K32C**; 6/23/05, 2157	Outer Chiniak Lagoon, no. of Cape Chiniak Lagoon	Hard-packed muddy fine sand; softshell clam, Baltic macoma	~+10	N58° 31.277' W153° 55.611'

APPENDIX C

Site No./ Date/ Time	Description of Site Location	Substratum; Dominant Bivalves Observed	Approx . Tidal Elev. (ft)	GPS Coordinates (NAD 27)
K33**; 6/23/05, 2148	Inner Chiniak Lagoon, no. of Cape Chiniak Lagoon	Very hard compact clay; no animals observed	~+10	N58° 31.407' W153° 57.204'
K34**; 6/23/05, 2155	So. Swikshak Beach, no. of Cape Chiniak Lagoon	Clean medium sand; young razor clams	+1.8	N58° 31.710' W153° 55.046'
K34A**; 6/25/05, 1150	Swikshak River delta	Clean medium sand; no bivalves observed	-3.1	N58° 35.682' W153° 47.807'
K34B**; 6/25/05, 1220	Swikshak Beach	Clean medium sand; young Alaska razor clams	~+2.0	N58° 35.866' W153° 47.137'
K34C**; 6/25/05, 1320	Big River delta	Medium/coarse sand flat, rippled; sparse 0- and 2- year-old razor clams	-2.0 & above	N58° 34.980' W153° 51.761'
K34D**; 6/25/05, 1310	Big River delta	Medium/coarse sand flat, rippled; no bivalves observed	-2.0 & above	N58° 35.009' W153° 51.610'
K35A**; 6/25/05, 1100	Shakun Islets	Coarse sand mixed w/cobble, considerable shell debris from butter and surf clams; no bivalves observed	-2.4	N58° 34.399' W153° 43.251'
K35B**; 6/25/05, 1130	Shakun Islets, sand bars	Clean medium sand; young Alaska razor clams	-2.4	N58° 34.359' W153° 43.376'
Northern Region				
K36A**; 6/24/05, 1025	Partially exposed sand beach in SW corner of Sukoi Bay	Fine clean sand w/ripples, scattered cobble, little shell debris; surf & Alaska razor & Alaska great-tellin	-3.3	N58° 51.824' W153° 19.518'

APPENDIX C

Site No./ Date/ Time	Description of Site Location	Substratum; Dominant Bivalves Observed	Approx . Tidal Elev. (ft)	GPS Coordinates (NAD 27)
K36B**; 6/24/05, 1100	Channel in entrance to Sukoi Lagoon	Fine clean sand flat; <i>Macoma</i> sp.	~-2.5	N58° 51.882' W153° 20.195'
K36C**; 6/24/05, 1130	Sand beach N of boulder pile in SW corner of Sukoi Bay	Fine clean sand flat; <i>Macoma</i> sp.	-3.3	N58° 51.940' W153° 19.868'
K37*; 6/24/05, 1200	Lagoon in W end of Sukoi Bay	Very poorly sorted sand w/silt/clay; softshell clam, Baltic macoma	~+8.0	N58° 51.776' W153° 21.003'
K38**; 6/24/05, 1010	Sand/gravel beach between no. point by island and Sukoi Bay	Sand flats; no shells obvious from air	-2.9	N59° 03.173' W153° 39.807'
K39**; 6/24/05, 0930	W. bight, Douglas Reef island	Fine hard-packed sand w/mud veneer; softshell clam and Baltic macoma	~+9.0	N59° 05.007' W153° 42.914'
K40A**; 6/24/05, 0904	Douglas Reef, No. of island	Coarse sand/pebble flat, highly disturbed, considerable broken surf & razor clam & cockle shell; no bivalves observed	~+8.0	N58° 05.358' W153° 43.781'
K42**; 6/24/05, 0950	Reef offshore of Douglas River	Flat algae-covered sandstone reef; no bivalves observed	Prob. >MLLW	N59° 06.270' W153° 55.345'

* Some samples collected

** Samples not collected

APPENDIX D

Sediment descriptions and characteristics at sampling locations in LACL, KEFJ, and KATM in summer 2004 and 2005. Sites are ordered from south to north within the respective regions.

Site ID	Median Diameter (µm)	Silt/Clay (%)	TOC (%)	TKN (mg/Kg)	C:N Ratio	Sediment Description
Lake Clark National Park and Preserve						
S21	0.15	2.6	0.070	271	2.58	Moderately well sorted sand
W22	0.07	48.9	0.360	350	10.29	Extremely poorly sorted gravelly, sandy silt
W8A	0.01	83.4	0.650	394	16.5	Very poorly sorted clayey silt
S8	0.05	58.3	0.340	378	8.99	Very poorly sorted sandy silt
M7	0.35	0.2	0.050	636	0.79	Moderately well sorted sand
SG2	0.11	0.4	0.060	140	4.29	Well sorted sand
M2	0.17	0.3	0.030	170	1.76	Well sorted sand
SG1	0.17	0.7	0.040	579	0.69	Well sorted sand
W1	0.13	32.1	0.08	215	3.72	Poorly sorted silty sand
Average	0.14	25.2	0.187	348.1	5.51	
Kenai Fjords National Park North & West Arms, Nuka Bay						
W50	1.93	8.8	0.43	856	5.02	Very poorly sorted sandy gravel
W49	6.96	7.3	0.83	1300	6.38	Very poorly sorted sandy gravel
W51	0.09	38.1	0.67	663	10.11	Very poorly sorted silty sand
W46	0.52	2.5	0.53	ND	-	Very poorly sorted gravelly sand
S31	2.93	0	0.33	ND	-	Poorly sorted sandy gravel
W47	10.93	0.9	0.33	560	5.89	Very poorly sorted sandy gravel
W38	2.07	2.2	0.53	426	12.44	Very poorly sorted sandy gravel

APPENDIX D

Site ID	Median Diameter (µm)	Silt/Clay (%)	TOC (%)	TKN (mg/Kg)	C:N Ratio	Sediment Description
W48A	0.60	2.4	0.65	93.3	69.67	Very poorly sorted gravelly sand
SG111A	0.68	1.2	2.3	91.3	25.19	Very poorly sorted gravelly sand
SG153	0.54	0.1	0.37	200	18.5	Very poorly sorted gravelly sand
SG146	0.26	0.2	0.37	392	9.44	Poorly sorted sand
W53	4.14	0.7	0.5	255	19.61	Very poorly sorted sandy gravel
Average	2.64	5.4	0.653	483.7	18.23	
McCarty Fjord						
SG122	0.058	52.5	0.31	525	5.9	Very poorly sorted sandy silt
W42	0.026	83.5	0.38	108	35.19	Very poorly sorted sandy, clayey silt
SG121	7.73	1.3	0.29	770	3.77	Poorly sorted sandy gravel
W39	0.37	5.3	0.45	800	5.63	Very poorly sorted gravelly sand
SG115A	1.275	28.0	1.01	1030	9.81	Extremely poorly sorted muddy, sandy gravel
S24	6.964	0	0.33	747	4.42	Poorly sorted gravelly sand
S24SG	0.93	0.1	0.33	311	10.61	Very poorly sorted gravelly sand
SG103	8.88	0.1	0.38	389	9.77	Poorly sorted sandy gravel
W36A	0.241	24.7	0.51	162	31.48	Very poorly sorted silty, gravelly sand
W36B	5.66	0.9	0.42	386	10.88	Very poorly sorted sandy gravel
Average	4.71	19.6	0.441	522.8	12.75	
Northwestern Fjord						
M2A	0.23	0.4	0.07	544	1.29	Moderately well sorted sand
SG43	0.159	7.0	0.16	969	1.65	Well sorted sand
S11	1.19	1.2	0.11	494	2.23	Poorly sorted gravelly sand
M2	1.189	0.4	0.11	442	2.49	Very poorly sorted

APPENDIX D

Site ID	Median Diameter (µm)	Silt/Clay (%)	TOC (%)	TKN (mg/Kg)	C:N Ratio	Sediment Description
						gravelly sand
W15	2.639	1.6	0.05	255	1.96	Very poorly sorted sandy gravel
M5	1.320	1.9	0.55	368	14.95	Very poorly sorted gravelly sand
W26	0.34	15.8	0.73	884	8.26	Very poorly sorted sand
Average	0.59	4.0	0.254	565.1	4.69	
Aialik Bay						
W10	8.574	0.6	0.31	ND; 2*	-	Poorly sorted sandy gravel
M1	0.48	0.3	0.3	1070	2.8	Poorly sorted gravelly sand
SG32A	0.97	0.1	0.32	900	3.56	Poorly sorted gravelly sand
SG31	2.549	1.5	0.41	1290	3.18	Very poorly sorted sandy gravel
SG30	0.04	12.9	0.8	589	13.58	Very poorly sorted gravelly sand
G1	3.864	0.3	0.29	ND; 20	-	Moderately well sorted sandy gravel
G1A	7.727	2.9	0.65	241	26.97	Very poorly sorted sandy gravel
W9	4.14	0.8	0.39	533	7.32	Poorly sorted sandy gravel
SG11	7.464	1.4	0.58	1300	4.46	Poorly sorted gravel
SG3	1.320	0.2	2.78	1590	17.48	Very poorly sorted gravelly sand
Average	1.41	2.1	0.616	827.7	12.35	
Katmai National Park and Preserve						
TN (%)*						
K37	0.24	30.2	0.61	0.05	12.2	Very poorly sorted silty sand
K31	0.32	0.7	0.12	ND	—	Moderately well sorted sand
K30	0.90	0.1	0.05	ND	—	Well sorted sand
K28	1.61	0.1	0.05	ND	—	Poorly sorted sand
DC	0.14	30.2	1.10	0.13	8.5	Moderately well sorted silty sand

APPENDIX D

Site ID	Median Diameter (µm)	Silt/Clay (%)	TOC (%)	TKN (mg/Kg)	C:N Ratio	Sediment Description
K19	0.36	0.1	0.08	ND	–	Well sorted sand
K22	0.37	1.8	0.14	ND	–	Well sorted sand
KC	0.43	0.5	0.26	0.02	13.0	Well sorted sand
K18	0.64	0.2	0.03	ND	–	Well sorted sand
K10	0.62	2.0	0.13	ND	–	Well sorted sand
K8	0.67	0.2	0.10	ND	–	Very well sorted sand
K21	0.40	5.6	0.17	ND	–	Moderately well sorted sand
K12	0.55	5.2	0.61	0.07	8.7	Moderately well sorted sand
Average	0.6	5.9	0.3	0.07	10.6	

- Measurement is total nitrogen rather than total Kjeldahl nitrogen; ND =Below level of detection of 0.01 percent for total nitrogen.

APPENDIX E and F

APPENDIX E Macrofaunal bivalve abundance from $\frac{1}{4}$ m² excavation samples.

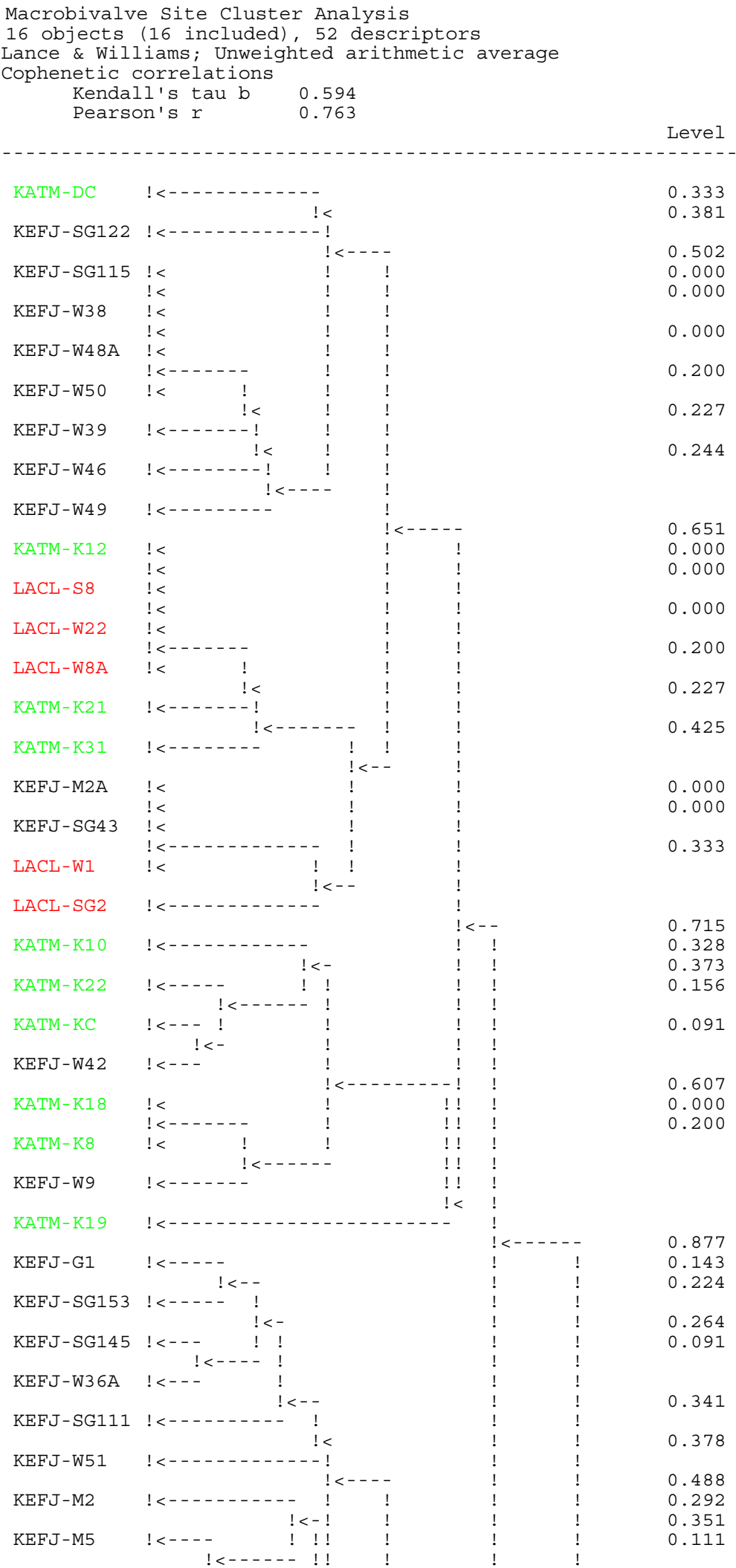
APPENDIX F Microinfaunal bivalves from 0.0081 m² core samples

Appendices E and F of bivalve abundances by site are formatted as legal-sized tables. Due to the change in format, they are attached as a separate document.

APPENDIX G

In the dendrograms showing relationships among sites, sites for the parks are color coded. KEFJ sites are black, LACL sites are red, and KATM sites are green

Appendix G-1 Dendrogram demonstrating relationships between sites on the basis of macrobivalves from excavation samples in SWAN parks.



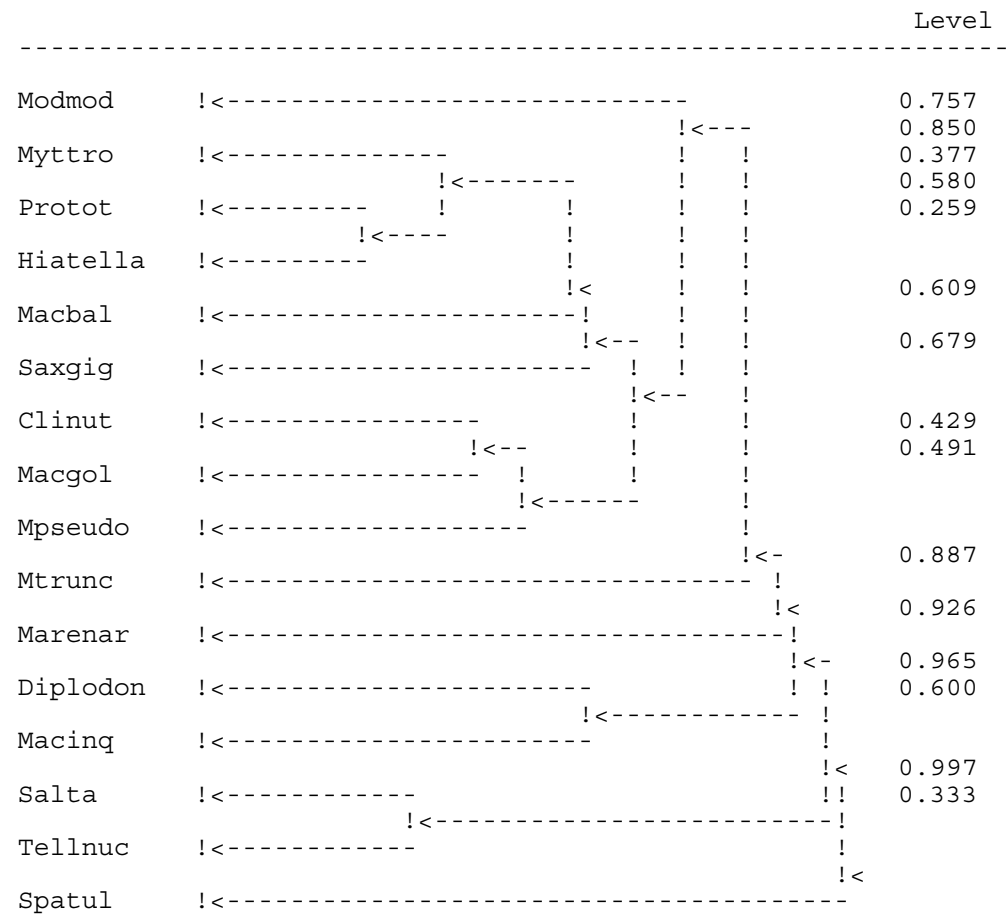
APPENDIX G

KEFJ-W26	!<-----	!!	!	!	!	
KEFJ-S11	!<-----	!<	!	!	!	0.125
	!<---	!	!	!	!	0.200
KEFJ-W36B	!<-----	!	!	!	!	
	!<-----	!	!	!	!	
KEFJ-SG121	!<-----		!	!	!	
		!<--	!	!	!	0.569
KEFJ-G1A	!<-----		!	!	!	
		!<---	!	!	!	0.669
KEFJ-S24SG	!<-----		!	!	!	0.333
	!<--	!	!	!	!	0.417
KEFJ-W47	!<-----	!	!	!	!	
		!<-----	!	!	!	
KEFJ-SG31	!<-----		!	!	!	
		!<-	!	!	!	
KEFJ-SG3	!<-----		!	!	!	0.429
	!<-----		!	!	!	
KEFJ-SG30	!<-----				!	
				!<---	!	0.987
KATM-K28	!<-----			!	!	0.500
		!<-----		!	!	0.750
KEFJ-W53	!<-----			!	!	
				!<-----	!	
KATM-K30	!<-----			!	!	0.333
	!<-----				!	
LACL-S10	!<-----				!	
					!<	
LACL-M7	!<				!	0.000
	!<				!	0.000
LACL-S21	!<				!	
	!<-----					
LACL-SG2	!<					

APPENDIX G

Appendix G-2 Dendrogram demonstrating relationships between species on the basis of macrobivalves from excavation samples in SWAN parks.

Macrobivalve Species Cluster Analysis
16 objects (16 included), 52 descriptors
Lance & Williams; Unweighted arithmetic average
Cophenetic correlations
 Kendall's tau b 0.709
 Pearson's r 0.908



SPECIES KEY

<u>SPECIES CODE</u>	<u>COMMON NAME</u>
Modmod	Northern Horsemussel
Myttro	Foolish Mussel
Protot	Littleneck Clam
Hiatella	Arctic Hiatella
Macbal	Baltic Macoma
Saxgig	Butter Clam
Clinut	Basket Cockle
Macgol	Oval Macoma
Mpseudo	False Softshell Clam
Mtrunc	Truncate Softshell Clam
Marenar	Softshell Clam
Diplodo	Rough Diplodon
Macing	Pointed Macoma
Salta	Alaska Razor Clam
Tellnuc	Salmon Tellin
Spatul	Pacific Razor Clam

APPENDIX G

Appendix G-3 Dendrogram demonstrating relationships between sites on the basis of microbivalves from core samples in SWAN parks.

Microbivalve Site Cluster Analysis
44 objects (44 included), 11 descriptors
Lance & Williams, Unweighted arithmetic average
Cophenetic correlations
Kendall's tau b 0.659
Pearson's r 0.809

		Level
KATM-DC	!<-----	0.333
	!<---	0.416
KATM-K31	!< ! !	0.000
	!< ! !	0.000
KATM-K37	!< ! !	
	!<-----	
LACL-S8	!< !	
	!<	0.462
KATM-K30	!< !!	0.000
	!< !!	0.000
KEFJ-SG43	!< !!	
	!< !!	0.000
LACL-M2	!< !!	
	!< !!	0.000
LACL-SG2	!< !!	
	!< !!	0.000
LACL-W1	!< !!	
	!< !!	0.000
LACL-W22	!< !!	
	!< !!	0.000
LACL-W8A	!< !!	
	!<-----	0.333
LACL-W11	!< !!	
	!<---	
KEFJ-W50	!<-----	
	!<---	0.545
KATM-K12	!< ! !	0.000
	!< ! !	0.000
KEFJ-M2A	!< ! !	
	!< ! !	0.000
KEFJ-W39	!< ! !	
	!< ! !	0.000
KEFJ-W48A	!< ! !	
	!<-----	0.200
KEFJ-W49	!< ! !	
	!<--	0.286
KEFJ-SG115	!<-----	
	!<---	0.378
KEFJ-M2	!<-----	0.143
	!<---	
KEFJ-M5	!<-----	
	!<--	
KEFJ-W26	!<-----	
	!<-----	0.821
KATM-K21	!<-----	0.200
	!<-----	0.417
KATM-KC	!<-----	
	!<---	
KATM-K22	!<-----	
	!<---	0.922
KATM-K28	!<-----	0.200
	!<-----	0.417
KEFJ-SG153	!<-----	
	!<-----	0.598
KEFJ-G1	!< !	0.000
	!<-----	
KEFJ-W38	!< !	
	!<---	0.724
KEFJ-S11	!<-----	0.200
	!<---	0.306
KEFJ-S24-S	!< !	0.000
	!<-----	
KEFJ-SG31	!< !	
	!<-----	0.490
KEFJ-SG121	!< !	0.000
	!<-----	0.143
KEFJ-SG122	!< !	
	!<---	0.278
KEFJ-W36A	!<-----	
	!<	
KEFJ-W36B	!<-----	
	!<---	
KEFJ-W9	!<-----	
	!<---	
KEFJ-SG146	!<-----	0.676

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KEFJ-W42	!<-----	!<-	!	0.200
	!<-----	!	!	0.467
KEFJ-W46	!<-----	!	!	
		!<-----	!	
KEFJ-W51	!<-----		!	
			!<--	1.000
KATM-K10	!<-----		!	0.600
		!<-----	!	
KATM-K18	!<-----		!	
			!<	
KATM-K19	!<-----			

Appendix G-4 Dendrogram demonstrating relationships between species on the basis of microbivalves from excavation samples in SWAN parks.

Microbivalve Species Cluster Analysis
11 objects (11 included), 44 descriptors
Lance & Williams; Unweighted arithmetic average
Cophenetic correlations
 Kendall's tau b 0.543
 Pearson's r 0.688

		Level			
Mytros	!<-----	0.510			
	!<-----	0.756			
Mbalth	!<-----	!			
		!<--	0.816		
Turton	!<-----	!			
		!<-	0.853		
Myaare	!<-----	!			
		!<			
Axiser	!<-----	!	0.556		
	!<----	!	0.663		
Macing	!<-----	!			
		!<--	!	0.728	
Rochtu	!<-----	!	!	!	0.455
	!<-----	!	!	!	0.607
Hiatel	!<-----	!	!	!	
		!<--	!	!	
Macgol	!<-----	!	!		
		!<----			
Protot	!<-----	!			0.455
	!<-----				
Saxido	!<-----				

SPECIES KEY	
<u>SPECIES CODE</u>	<u>COMMON NAME</u>
Mytros	Foolish Mussel
Mbalth	Balthic Macoma
Turton	Minute Turton
Myaare	Softshell Clam
Axiser	Silky Axinopsid
Macing	Pointed Macoma
Rochtu	Robust Mysella
Hiatel	Arctic Hiatella
Macgol	Oval Macoma
Protot	Littleneck Clam
saxido	Butter Clam

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Considerations Regarding Methodologies in Long-term Monitoring Program

Based on our experiences in sampling soft substrates during this program and since 1976, we are presenting several considerations regarding methodologies for a long-term monitoring program in the SWAN parks. These include suggestions of objectives that we consider to be achievable and discussions of several sampling design issues, population sampling techniques that we have found effective, tissue sampling issues, and finally suggestions regarding environmental monitoring.

Objectives

Primary objectives of a long-term monitoring program should be to establish time-series data for abundance (density) and size structure of: 1) key predators in the ecosystem being monitored; 2) several prey species that are key to ecological interactions in this system; and 3) contaminant loading in these predator and prey species. In the proposed long-term monitoring program for SWAN, we assume the predator data will be obtained in separate elements of the overall program. In the discussion below, we are limiting our suggestions to major prey species, especially bivalves. We believe it would be useful to monitor species representative of all major biologically significant sediment types found in the respective parks (i.e., not just mussel outcrops).

Secondary objectives are to collect supplemental data that will assist in evaluating changes in abundance or size structure in the prey populations. These types of data include:

- Predator activity and effectiveness;
- Beach profiles;
- Sediment conditions; and
- Water quality.

Monitoring programs often choose to focus on either population dynamics OR contaminant chemistry. Combining the two goals may not be mutually optimal. In Alaska, other than unique catastrophic events (EVOS) or in the vicinity of human habitation, the limited current data (EMAP, MMS, LTEMP) show virtually no contaminant impact from anthropogenic sources within SWAN. On the other hand, natural climatic change appears operative (e.g., decadal oscillations) or imminent (e.g., global warming). SWAN resource managers will need to decide which aspects have highest priority and adopt methodologies that provide the most appropriate management information. We have provided suggestions for both aspects in the sections below.

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Desirable Features for Long-term Monitoring Program

As is often noted by program managers, “coastal resource monitoring programs can be costly and complex”, but not all species or habitat variables are equally valuable or useful for long-term monitoring. The goal then is to select variables that not only provide useful information for both scientific and management viewpoints but which are cost-effective. Thus, by selecting and monitoring fewer, more appropriate species and variables, the spatial extent of monitoring can be extended and site-specific replication increased.

Besides providing a characterization of the bivalve assemblages and an assessment of habitat quality in three SWAN parks, one intent of this study was to define options and provide information that would assist in the design of a repeatable, quantitative monitoring program. Suggestions contained herein and species/site relationships in Appendix G will facilitate design of a program capable of detecting long-term changes in biota and habitats resulting from effects of acute or chronic human actions (e.g., oil spills, chemical contaminants such as DDT or PCBs, or global warming), altered water quality, geomorphic processes, or cataclysmic natural events (e.g., volcanic eruption, seismic events, or tsunamis). The imminence of any of these types of disturbances is relatively high, on a human scale, all having occurred regionally within the last several decades.

Important considerations in the design and implementation of a long-term monitoring program include:

- 1) A scope of work that addresses the major issues of concern, i.e., changes in abundance of relevant major prey species, size structure and/or biomass, and contaminant loading in the prey species;
- 2) Effective sampling in appropriate habitats;
- 3) Simple and efficient but appropriate sampling and analytical methodologies;
- 4) Sensitivity of the sampled populations to a variety of types of change; and
- 5) Cost.

Needless to say, each of the first four considerations has cost implications. Also, considerations folded into items 1 through 3 and cost include required field time (number of days per survey and surveys per year or decade) and the need for analytical testing, its sensitivity, and associated costs.

Sampling design

The number of sites sampled should vary with the objective of the long-term sampling program. Design depends on whether the desire is to make regional comparisons among the parks (a few sites in each park will suffice) or is there a desire to examine the effect of tourist activity, e.g., gradients in PAH

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contamination across KEFJ from vessel traffic supporting tourism with proximity to Seward, the gateway to the park. The latter case would require more effort.

Initial site selection should be non-random. The general sampling locations should be selected following a reconnaissance survey in areas where the sentinel species is relatively abundant. It is imperative that GPS coordinates be recorded for areas of high abundance to assure that samples and data collected during subsequent surveys is from the same location ($\pm$ GPS error). The goal is to sample the same population during each consecutive survey.

Replication of sampling locations for each species in a park is desirable. If possible, it would be prudent to select the three best locations for each species in each park after examining at least six alternative sites during the reconnaissance. This may be difficult or not possible with some species.

Following selection of the general locations, sites should be sampled randomly during the subsequent monitoring surveys with the goal of statistically representing the site populations. One effective approach is to have samples or observations positioned randomly along transect lines laid out with specific relationships to the base point established at the original GPS coordinates. Depending on the sampling techniques employed at each site, this may require setting up one or more transect lines at the sites. Each type of sampling should be conducted on a different transect line to avoid interference. Moreover, the random numbers employed should be established for all surveys before the first survey is initiated and, for destructive sampling, no number (location) should be used again in subsequent surveys.

Recommended suitability criteria for sampling techniques:

- 1) Simple to perform while producing replicate quantitative results. Does not require complex equipment.
- 2) Size of sampling plot is large enough to provide adequate numbers of individuals in each sample plot and produces a minimum number of empty samples (zero observations).
- 3) Not labor-intensive, performed with a small crew because of logistical limitations and expense. Does not require considerable laboratory effort to complete sample analysis (excepting chemical analyses).

Population Sampling Techniques

Based on the discussions above regarding the ability of various methodologies to produce useful information, we recommend that the long-term monitoring program utilize macrofaunal bivalves to achieve its monitor objectives for prey populations. The organisms are best sampled with either excavation sampling or enumerating surficial cues (burrow “shows” or fecal deposits) in quadrats or band transects of appropriate sizes. The choice of whether to excavate or rely on visual counts in quadrats or band transects depends on a few important considerations. If densities are high, as in a mussel bed, the most efficient

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approach is to excavate the animals and count and measure them back at the staging area rather than waste precious time during the low tide window. If the substrate does not allow accurate enumeration of burrows (e.g., in mixed-soft sediments) or if multiple species are involved, it is again best to excavate. However, if it is clear that an area supports only one or two species and the burrows are clearly defined and species specific, or densities are relatively low, the best choice is probably visual enumeration of the surficial cues using either quadrats or band transects. The latter situation often occurs on mud or sand flats.

On mud flats, washing samples often consumes considerable precious time during the low-tide window, influencing the decision to avoid excavation. On sand flats, washing is generally rapid but the low density of animals reduces the cost-benefit of excavation. Consequently, band transects become a favored option. In some instance, conducting both excavation and visual surveys is important particularly since visual surveys do not produce tissue samples or data on size structure. However, visual surveys do allow the researchers to cover a far larger area and consequently, those density estimates are probably more representative of the larger scale of shoreline. However, the analysis in the Results section suggesting that the results of visual surveys are quite conservative (up to 50-percent low) should be factored into final density estimates.

Whenever visual survey techniques are chosen, the investigators should dig up several specimens of the species in the survey area to determine or confirm their identification. This is particularly important in areas that support softshell clams because researchers can easily confuse the three major species on the basis of surficial cues.

Excavation Sampling

Generally, our findings above have shown that the data obtained from excavation sampling are far superior for the stated purposes than those obtained from core sampling. Excavation sampling emphasizes the larger, more mature but rarer component of the infauna whereas core sampling emphasizes the smaller components and the short-lived species (weeds). Moreover, in the types of habitats that this program will focus on, a much larger percentage of the core samples are devoid of bivalves that were in the excavation samples. Furthermore, considerably more time is required to process core samples than excavation samples. Finally, excavation sampling can produce many of the specimens that would be required for a tissue sampling program, thus eliminating or reducing one field task.

Depending on the density of the target species, we recommend either a $1/16\text{-m}^2$ or a $1/4\text{-m}^2$ quadrat constructed of Schedule 40 PVC pipe. For mussel beds, we recommend removing the mussels by hand from $1/16\text{-m}^2$ quadrats. For most other species, where density is much lower, we recommend excavating the sediment with a shovel or trowel from within the boundaries created by $1/4\text{-m}^2$

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quadrats. Excavated sediments can be sieved through screens constructed with standard ¼-inch hardware cloth.

Power analysis, using site-specific, park-specific data for selected species based on replicate information from this project, indicates that the ability to detect change will benefit from working with populations with reduced sampling variability (Figure H-1). Moreover, these data for Baltic macoma from the SWAN parks also indicate that the number of samples required for better detection of change is reduced at higher densities (Figure H-2). The implications from these figures are that sites with high density and homogenous distribution should be given preference during the site selection process. The estimates for numbers of samples in these figures were based on detecting a 25-percent effect and assuming $\alpha = 0.10$ with a parametric 2-tailed test.

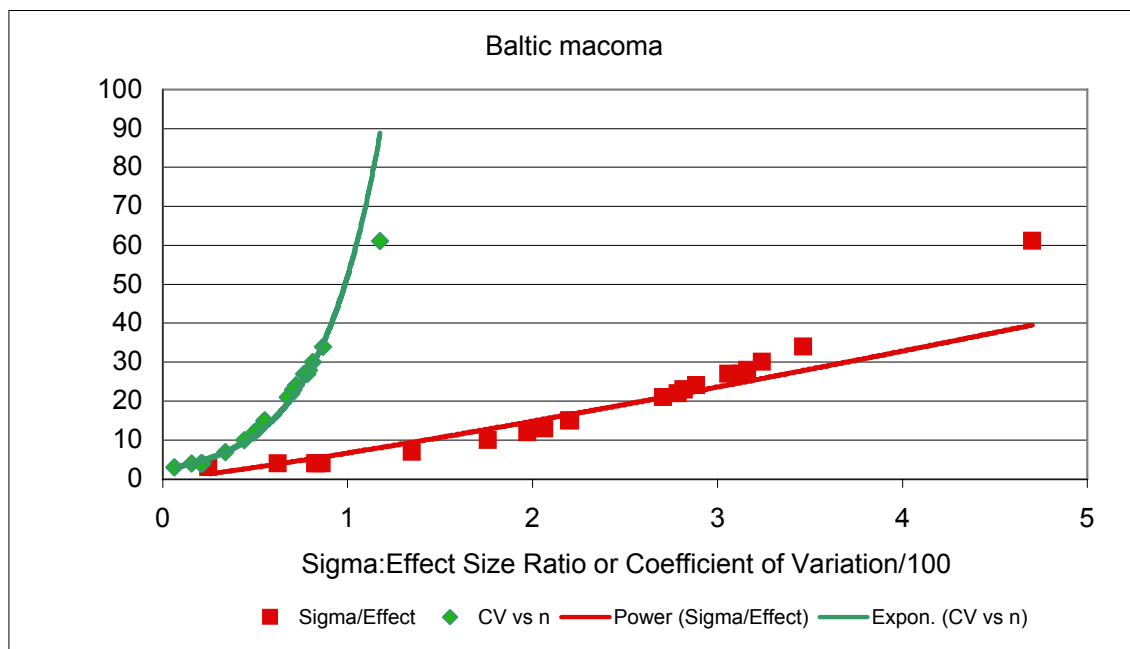


Figure H-1. Relationships between estimated numbers of samples required to satisfy sampling design criteria and either the sigma/effect size ratio or the coefficient of variation/100 for Baltic macoma in ¼-m² excavation samples.

The term “sigma”, used in discussions of power analysis, is synonymous with the standard statistical term, “standard deviation”. Thus, both curves in Figure H-1 examine the response of the estimated number of samples needed to achieve a moderate chance of detecting a 25-percent change in density to the variability observed among populations sampled. Based on these curves, when the standard deviation of the samples for a population is more than about half as large as the mean, or more than 30 percent greater than the anticipated effect size, the required number of samples to achieve a 50-percent chance of rejecting an incorrect null hypothesis will exceed ten.

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With regard to density of Baltic macomas, the curve in Figure H-2 suggests that densities of that clam must exceed about 260/m² before sampling will reliably detect a 25-percent change.

Consequently, we recommend that similar analysis be completed for all sites considered for excavation sampling. Completing ten excavations at any site would be a considerable task but could be accomplished. However, sampling more plots would be quite burdensome and is not realistic. Moreover, the size of the area necessary to sustain such an intensive protracted sampling program increases the difficulty of selecting an appropriate site.

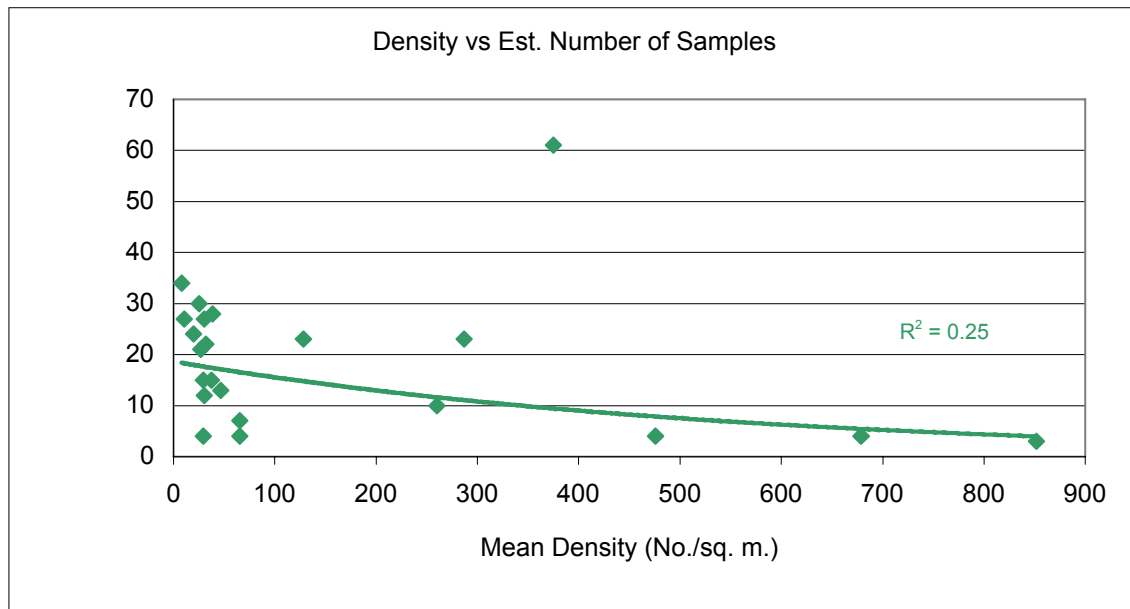


Figure H-2. Relationship between Baltic macomas density in ¼-m² excavation samples and estimated numbers of samples required to detect 25-percent change.

Band Transects and Quadrats

In areas where siphons or biogenic activities of individual organisms produce distinguishable surficial cues, using band transect or quadrat sampling techniques can provide a considerable amount of data in an efficient manner. Most of the data in Table 10 above, representing a variety of sites and for a variety of species or surficial cues, were collected in 15-20 minutes per site. In some cases, data were collected on two or more items (e.g., softshell clams and fat innkeeper worms at KATM - K37). Because these samples can be completed so rapidly, power analyses indicating large numbers of replicate samples are not as intimidating as such numbers would be for excavation samples. This type of sampling produces considerable “bang for the buck” where it is feasible. We employed a variety of dimensions for sampling plots during these surveys. Each size was chosen with the intent of optimizing the effort. The primary item that can be gleaned from these data is that it is advisable to sample as many

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replicates as possible, regardless of the method. Furthermore, it is advisable to select plot dimensions that produce as few zero values as possible.

We employed a variety of dimensions for sampling plots during these surveys. Each size was chosen with the intent of optimizing the effort. For softshell clams, densities measured with quadrats or band transects ranged from 0.23 to 11.4 clams/m² (Table 10 above). For Pacific razor clams, densities ranged from 0.35 to 2.49 clams/m².

Where we had data from both excavation samples and band transects, we compared density estimates. In all but one case, the density estimates from excavation samples were appreciably higher than those observed in the band transects. Considering that “shows” observed during visual sampling are sometimes obscured by algae, etc., and excavation sampling detects smaller animals than are comfortably identified during band-transect sampling, this difference is understandable. Overall, excavation estimates were about 50 percent higher than band-transect estimates, but the differences appeared to be considerably greater for razor clams than for softshell, butter, and littleneck clams. With razor clams, the “shows” are often obscured by water standing in the ripplemarks left in the sand by the waves or the clams are still inactive and have not yet re-opened their burrows. The implication is that band-transect sampling provides a conservative estimate of the actual density for the target species and is limited to the larger size fraction of the population.

Sampling Frequency

Regarding sampling frequency, because the sentinel species are all relatively long-lived, it seems acceptable to sample once per year, at least during the first several years. Sampling events should be coordinated to occur at approximately the same time during the same season each year. Provided that populations appear relatively stable over a period of several years, it may be acceptable to cut sampling frequency back to every two or three years. However, if a major catastrophic (spill, seismic or volcanic) event occurs during a period when sampling was not scheduled, a strong effort should be made to sample as soon as possible to assess the effects resulting from the event.

If there is a desire in the program to examine growth rates of some of the species, sampling frequency should to be increased to at least three times per year unless either chemical or physical tagging techniques or planted enclosures are employed. The latter three approaches produce the more reliable data and require far fewer specimens.

Tissue Contamination

Tissue sampling will be an important component of the long-term monitoring program. It will allow park managers to monitor the effects of globally distributed contaminants such as chlorinated hydrocarbons as well as hydrocarbons associated with fuels or oil spills that have a more local origin.

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EPA and local agencies have specific protocols for the collection of tissue samples. These must be reviewed and implemented to ensure that the samples are properly collected and handled during processing, or transport to the laboratory for analysis. Generally, specimens intended for tissue testing should be collected in a manner that is careful to avoid contaminating them with substances from the vessels or helicopter or substances used by the collector (e.g., sun screen or bug dope). The collector should wear surgical gloves when handling them. Broken specimens should be discarded. Acceptable specimens should be washed to remove sediments, segregated by species, packaged in aluminum foil, and placed in clean, labeled Ziploc bags. The labeled packages should then be placed in a dedicated, chilled ice chest for transport to the staging area for further processing.

If tissue burdens are the goal, an important process that is often overlooked is depuration, i.e., the process of “soaking” the collected animals in fresh clean seawater for about 24 hours to allow them to purge contaminants contained in food materials in their intestinal tract. This is especially important when testing for petroleum hydrocarbons in areas with appreciable vessel activity or after an oil spill. In these cases, considerable concentrations of the target hydrocarbons can be associated with the ingested food particles and that could bias the results of tissue analysis.

It is crucial to plan and prepare for depuration prior to embarking for the field for a monitoring survey. Equipment must be available to provide a reliable flow of seawater to the depurating animals for the entire period and the equipment must have the capacity to handle the volume and number of samples that are collected.

It is also crucial to plan to freeze and store these specimens in a timely manner. Specimens collected for chemical analysis should be frozen whole and maintained in the frozen condition until they are pulled from the freezer by the analytical laboratory for processing. Again, broken specimens should be discarded.

Generally, because of the high cost of tissue chemistry it has become acceptable to analyze composite samples for tissue analysis. It is desirable, in this case, to have the sample comprise several specimens collected from different areas within the sampling location.

Annual sampling should be adequate for tissue sampling and, after several years, if tissue burdens are stable, cutting back to every two or three years would probably be acceptable except in areas like Aialik Bay, where vessel activity associated with seasonal tourism is growing and has the potential to affect the intertidal resources.

Another consideration as other monitoring programs continue or come on line is the potential for taking advantage of sharing the data from existing or new contaminant monitoring programs (e.g., the PWS RCAC LTEMP, EMAP, and, to lesser extent, the developing CIRCAC monitoring program). Eventually, the

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EVOS GEM program may provide long-term contaminant monitoring in Prince William Sound, the Gulf of Alaska, and parts of Cook Inlet.

Current data from these programs and earlier programs (e.g., Lees et al. 2001; Payne et al. 2005) show that except in the vicinity of significant human habitation, ambient conditions are near pristine in terms of hydrocarbons and PCBs. However, an easily distinguishable low background signal of hydrocarbons emanates from somewhere east of the Copper River and is transported by coastal currents to the end of the Alaska Peninsula (Saupe et al. 2006, Short et al. 1999, A. D. Little 2001). The signal seems to be embedded in particles of some form of hydrocarbon-bearing “source rock”, i.e., an oily shale or coal, which keeps the contaminant biologically unavailable (as evidenced by the lack of microbial weathering during transit). PAH signatures from natural oil seeps (e.g., in the vicinity of Oil Bay in Cook Inlet) are also locally detectable but these are easily distinguished from anthropogenic sources. Additionally, various heavy metals have been found in south-central marine sediments coming from natural mineral deposits (A. D. Little 2001, Saupe et al. 2006).

Environmental Monitoring

Several environmental factors important to community structure of epifaunal and infaunal bivalves on unconsolidated sediments should be described for each site and monitored along with the biological and contaminant variables. Frequency of monitoring varies considerably with the stability of the variable being monitored.

Biological factors important in influencing conditions at the sampling locations and in interpreting observed change include observations or evidence of predation by sea otters, brown and black bears, diving ducks, and shorebirds on the resources of concern. Quantification of predation intensity and prey species can provide useful insight into observed changes. This type of data can be quantified through quadrat and band-transect sampling (see bear/sea-otter feeding pits, for example, in Table 10 above) or actual field observations during foraging activities.

The long-term monitoring program will provide a useful opportunity to monitor for invasive bivalves. At present, softshell clams (*Mya arenaria*), a dominant species in mud flats in the region but considered by many to be an invasive species (e.g., Hines and Ruiz 2000²), was the only invasive bivalve observed in natural habitats in southcentral Alaska. If it is an invasive, it has become an important component of mud-flat assemblages in terms of structuring the habitat and as a food source for “charismatic” predators like brown bears and sea otters. The oyster *Crassostrea gigas* is cultured in aquaculture farms in Kachemak Bay but does not appear to be reproductive. The risk of invasion by other exotic bivalves appears low.

²Hines, A. H., and G. M. Ruiz (Editors). 2000. Marine invasive species and biodiversity of South Central [sic] Alaska. Prepared by Smithsonian Environmental Research Center for Regional Citizens' Advisory Council of Prince William Sound and U. S. Fish & Wildlife Service. 75 pp.

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Fixed physical factors that are determined by topography (e.g., exposure to wave action, swell, currents, beach profiles, and ice scour) should be described for each site and generally do not need to be re-examined unless geological events occur. Physical factors including sediment characteristics (i.e., particle size distribution patterns and organic carbon and nitrogen), and salinity of surface and interstitial waters should be sampled during each survey. If the sediment variables exhibit stability over several years, it is probably acceptable to reduce the sampling frequency although the analytical costs are generally low.

Among the water quality variables, interstitial salinity is probably a more important measurement because it changes more slowly and is more representative of the seawater milieu in which the clams are permanently immersed than widely fluctuating surface salinity. Because of the great range in water temperatures experienced seasonally, and diurnally on mud flats during the low tide window, the “snapshot” temperature measurements collected during such sporadic surveys are probably not of great value except in areas with freely flowing seawater. If a more comprehensive view of changes in water quality is desired, placing recording monitoring instruments at key facilities is an option that will provide long-term records for water temperature, salinity, and turbidity. Since an objective of the proposed long-term monitoring program is to search for changes related to climate change, the option of deploying recording water-quality instruments should be considered.

Geological factors important in understanding the observed development of and changes in infaunal assemblages in these parks include the historic or recent occurrences of earthquakes, volcanic activity, tsunamis, and glacial retreat. Once sampling locations are selected, the influence of each of these factors should be evaluated as an aid to future interpretation of changes observed at the sites. Our failure to locate populations of mature razor clams at Swikshak and Big River provides an example of the value of this type of analysis as it seems probable these previously commercially harvested beds may have been destroyed by the Great Alaska Earthquake of 1964. A similar disappearance of razor clams has been noted on the Copper River delta. This evaluation would need to be updated only as future geological events occur. It seems advisable that a qualified geomorphologist should prepare this initial geomorphologic description and should include and evaluation of sediment sources and “permanence” of the structures.

The sampling design of this program is conducive to Before-After-Control-Impact analysis if environmental events of anthropogenic activities (e.g., the Pebble mining prospect) introduce change over a relatively constrained period. Trend analysis is another option for long-term change such as global weather change. Various multivariate approaches should be employed to describe the communities and assess relationships among environmental covariates.

Finally, the program should include considerable photodocumentation, both initially and as the program progresses. The photographs are valuable for detecting or watching trends. A good example of important potential trends

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would be to use aerial photos of foraging pits of ducks, sea otters, and brown bears on beaches and mud flats to monitor foraging trends.